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Bulletin No. 34.

W. B. No. 311.

U. S. DEPARTMENT OF AGRICULTURE,  
WEATHER BUREAU.

# CLIMATE:

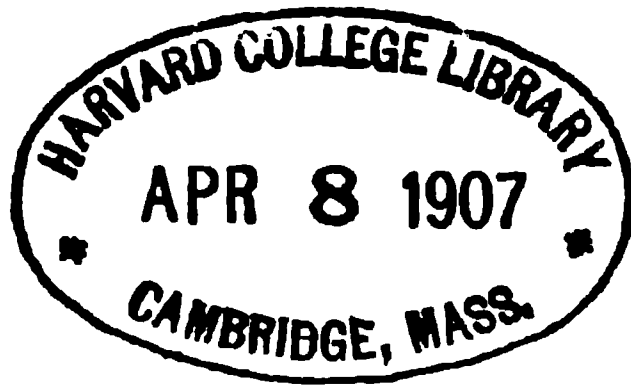
ITS PHYSICAL BASIS AND CONTROLLING FACTORS.

BY

WILLIS L. MOORE,  
CHIEF U. S. WEATHER BUREAU.

WASHINGTON:  
WEATHER BUREAU.  
1904.

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LETTER OF SUBMITTAL.

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U. S. DEPARTMENT OF AGRICULTURE,  
WEATHER BUREAU,  
*Washington, D. C., May 11, 1904.*

HON. JAMES WILSON,  
*Secretary of Agriculture.*

SIR: I have the honor to recommend that the inclosed article on Climate, written by me for the Encyclopedia Americana, be printed as a bulletin of the U. S. Department of Agriculture, Weather Bureau. The information contained in the article will doubtless be of value to the younger observers of the service, and to the layman who is not an expert in meteorological science.

Very respectfully, your obedient servant,

WILLIS L. MOORE,  
*Chief U. S. Weather Bureau.*

Approved:

JAMES WILSON,  
*Secretary.*



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## CLIMATE.

From the Greek word *κλίμα*, a slope or inclination. The term was used to denote the effect of the oblique rays of the sun on the temperature of the earth and its atmosphere. To-day it is applied to the sum of the atmospheric conditions as recorded for a long period of time; or, in other words, it is the totality of weather, while "weather" is the physical condition of the atmosphere at a given time, or during a limited period.

One may well speak of the weather to-day, or of last month, of some past year; but not of the climate of a day, a month, or a year. The climate of a place is ascertained by a study of its continuous weather records; for a long period of years—the atmospheric pressure, the temperature, the rainfall and snowfall, the time and frequency of frost, the extremes of heat and cold, the direction and velocity of the wind, the amount of air that flows from the different points of the compass, the amount and the intensity of sunshine, the humidity and transparency of the atmosphere, and its electrification.

The study of the causes of the weather and of the laws of storms constitutes that branch of science known as meteorology; climatology is to be considered as a subdivision of meteorology.

Climates may be broadly divided into marine, continental, mountain, and plain, with the many variations produced as these conditions gradually or precipitately shade off the one into the other.

*Basis of climate.*—If the axis of the earth's rotation were perpendicular to the ecliptic (the plane of its orbit) there would be no seasonal changes, for the rays of the sun would fall upon every point on a parallel of latitude with the same angle of incidence on each day of the year. There would be but one season at any place and it would never end, and there would be little variation in the intensity of storms. But as the axis of the earth is inclined at an angle of  $23.5^{\circ}$  to the plane of its orbit, and as the direction toward which it points remains



nearly constant, there are but two days in each year when both hemispheres (north and south) are exactly one-half in sunshine and one-half in darkness, i. e., at the vernal and autumnal equinoxes, when the sun crosses the equator. At all other times in each hemisphere, the angle at which the sun's rays strike the earth, the depth of the air through which they pass, the length of the day, and the proportions of each hemisphere immersed in sunlight, are increasing or decreasing. As these four conditions increase in the Northern Hemisphere after the vernal equinox the summer grows upon us, reaching its greatest degree of heat about four weeks after the summer solstice. The lag of temperature is due to the fact that the atmosphere, being heated mainly by radiation from the earth and comparatively little by the direct action of the solar rays, does not attain its greatest heat until after the land and water have reached their maximum temperature and in turn have communicated this heat to the air above. Up to June 21, or the summer solstice, the Northern Hemisphere receives each day more heat than it loses, otherwise it could not gain in temperature; after the solstice the sun each day at meridian is found to have receded a little to the south. At places north of the Tropic of Cancer its rays fall with increasing obliquity and pass through a greater depth of air, and impinge for a less time each day, so that within a few weeks the earth begins to radiate more heat each day than it received. The maximum heat of summer occurs, on the average, when the loss of heat from the earth is just equal to that gained during the day from the sun. This, as previously stated, occurs several weeks after the sun is well on its way southward. About September 21 the autumnal equinox occurs, when the sun crosses the equator, and, as at March 21, the days are of equal length at all latitudes of both hemispheres. On or about December 21—the winter solstice—the sun is farthest south, and the same conditions prevail in the Southern Hemisphere that prevailed in the Northern Hemisphere on June 21. North of the equator the sun is now least effective; its rays reach the earth at the lowest angle through the greatest depth of air, and they are operative for the fewest hours during each day, of any portion of the year, but the greatest cold does not occur. This comes about four weeks later, when the increasing heat received each day by the earth from the sun is just equal to that lost by radiation.

The effect of latitude will be understood by reference to the following figure:

FIG. 1.

As the latitude increases, the rays of the sun will fall with increasing obliquity, and they lose in power by being spread over a larger surface, and by traversing a greater depth of air, which absorbs more of their heat.

The same beam  $A$ , "when the sun is vertical, is spread over a surface such as  $CC$ . When the sun is inclined at an angle as shown in the figure, the beam is spread over a surface,  $C'C'$ , which is somewhat greater than the first, and it passes through a column of air,  $B'B'C'C'$ , greater than that of  $BBCC$ . The intensity of insolation at midday decreases approximately as the cosine of the latitude."

Near the equator the sun's rays at midday fall perpendicular to the surface of the earth, and there is virtually no change in the length of the day, and consequently there is little variation in the daily or seasonal temperature. As the variation in the length of the day increases with the latitude, there are regions, in the temperate zone, where the length of time that the sun's rays fall upon the earth each day more than compensates for their obliquity. On this account the interior of continents may have at midday a higher temperature than prevails at the equator.

Solar energy is about 7 per cent greater at perihelion (the point in the earth's orbit nearest the sun) than at aphelion (the point farthest away). As perihelion occurs in December, or the summer time of the Southern Hemisphere, and aphelion in its winter, that region has a greater range in the intensity of solar insolation than the Northern Hemisphere. If the land

surfaces of the two hemispheres were equal in area, the southern would have colder winters and warmer summers than the northern, and this is the case in portions of the Southern Hemisphere where the land area is large. But the great capacity of water for heat, and the slowness with which it radiates the same, modifies seasonal extremes that otherwise would be much greater.

*Variations in climate.*—If the earth were all water or all land, and if the land were everywhere of the same elevation, most of the factors that cause variations in climates—often considerable for regions closely contiguous—would be eliminated from the equation. Every point on the same parallel of latitude would have the same mean annual temperature, and the same average heat in summer and the same average cold in winter. New York and London, separated by eleven degrees of latitude, would not, as now, have about the same mean annual temperature. If it were all water there would be no such extremes of heat and cold as we now know. It is probable that a thermometer exposed in the shade four feet from the surface of the earth would not anywhere—even at the equator—ever register above  $90^{\circ}$  F.; there would be no frost within  $35^{\circ}$  or  $40^{\circ}$  of the equator, and zero temperatures would be recorded only in regions within  $30^{\circ}$  of the poles. If it were all land the heat would be much more intense than now in the Tropics, and in the temperate and frigid zones the heat of summer and the cold of winter would reach extremes unknown at this time.

All the anomalies of climates are caused by the different specific heat capacities of land and water; their different powers of conduction and radiation; the irregular distribution of these two surfaces; the widely-varying elevations of the land; the trend of mountain ranges; the prevailing direction of the winds, and the carrying of large quantities of heat by ocean currents from the equator toward the poles, and the relative quantities of cloud and rain or snow. It is germane to a proper understanding of climate to know something in detail of the manner in which the air is heated. At 100 or 200 miles above the earth's surface there is only the hypothetical ether, which, while too tenuous to be detected or measured by any methods or appliances so far known, is supposed to be the medium that transmits solar energy to the earth and diffuses it through space. This energy, coming in many different wave lengths and with widely-varying intensities

of vibration, produces several different phenomena as it is absorbed by or passes through the air, or as it impinges on the surface of the earth. The waves differ in their effects on different objects, depending on the length and the absorptive response of the substances upon which they fall. The waves have heating, lighting, and chemical effects simultaneously in themselves, and it is only the nature of the objects upon which they fall that tends to differentiate them. The atmosphere, even at the surface of the earth, absorbs but a small part of the heat waves. They, therefore, reach the earth and warm its surface; and the earth in turn, by radiation, convection, and conduction, sends back into the air long heat waves, which, unlike the shorter solar waves, are readily absorbed by the atmosphere. The atmosphere is thus warmed from the bottom upward. This accounts for the perpetual freezing temperatures of very high mountain peaks, although they are nearer the sun than are the bases from which they rise. At the height of one mile in free air the temperature is about the same at mid-day as at midnight. Only during recent years have we begun to realize how extremely thin is the stratum of air next the earth that has sufficient heat for the inception, growth, and maturity of both animal and vegetable life. The raising of the thermometer shelter at the New York City observatory from an elevation of 150 feet above the street to an elevation of 300 feet, has caused an apparent lowering of the mean annual temperature of  $2.5^{\circ}$  F. On the hottest day in summer, if one could be lifted up to the height of only 1000 feet in free air, he would find a marked change in temperature. The United States Weather Bureau at 16 stations made a total of over 1200 kite observations in the United States in 1897. They showed an average decrease of  $7.4^{\circ}$  F. for the first 1000 feet of ascent during the warm months, and when the observations were taken near the hour of daily maximum heat the decrease was frequently as much as  $15^{\circ}$ . At the height of 6 miles the cirrus clouds common to this level are, on account of the low temperature, always composed of minute ice spiculæ, never of watery droplets like the lower cumulus clouds. In the middle latitudes of both hemispheres the air at this height is ceaselessly rushing toward the east, passing uninterruptedly over the cyclonic and anticyclonic systems that cause our storms and cold waves at the surface of the earth. Glaisher and an assistant ascended to a height of about 30,000 feet.

They suffered greatly from the cold, which measured many degrees below zero, although the time of year was September 5. At the height of 6 miles the average temperature, determined by many balloon ascensions is about  $-60^{\circ}$  F.

The difference between continental and marine climates is marked. The same amount of heat will raise the temperature of a land surface four times as high as it will raise that of a water surface. Land is a good absorber and a good radiator, but it is a poor conductor and a poor reflector. The absorbed heat does not penetrate into the ground to any great depth. The land, therefore, retains its absorbed heat near the surface and quickly and freely radiates that which it has absorbed. These conditions give to large land surfaces much higher temperature during the day and much lower temperature during the night than obtain over a water surface of the same latitude and much colder winters and much warmer summers. As an illustration, it may be stated that the Bermuda Islands, in the North Atlantic Ocean, have a mean daily range of temperature of only  $10^{\circ}$  F., and an annual range of only about  $50^{\circ}$ ; while Memphis, Tenn., near the same latitude, in the interior of a large continent, has a daily range of  $17^{\circ}$  and an annual range of  $112^{\circ}$ . At Memphis a temperature of  $104^{\circ}$  has been recorded in summer and  $-8^{\circ}$  in winter. At Bermuda the temperature generally reaches  $90^{\circ}$  during the summer, but very rarely exceeds that figure, while temperatures below  $45^{\circ}$  are also very infrequent. The two places are typical of continental and of marine climates. All regions bordering closely on the sea partake of both climates, the predominating one being determined by the direction in which the coasts trend, their elevation, and the direction and force of the prevailing winds.

In the middle latitudes of both hemispheres the prevailing winds are from the west, and, therefore, continents lying in these regions have a marine climate in their western coastal regions, where the air moves from the water to the land, and nearly continental climate in their eastern coastal regions, where the general movement of the air is from the land to the sea.

The distance to which moist and equable air conditions extend inland is determined by the elevation of the land and its trend relative to the incident winds and the proximity of mountain ranges. The humid air from the Pacific meets the lofty range that skirts the western shore line of both North

and South America; it is forced up the mountain side until the cold of high elevation and the cooling of the air by expansion as it ascends cause it to precipitate its moisture, mostly upon the western side of the mountain, and it passes to the interior of the continent bereft of that life-giving moisture which, were it not for the intervention of the mountains, would spread a mantle of luxuriant vegetation 1000 miles inland. If the disintegrating effects of temperature and rainfall had worn down the Sierras, the Plateau, and the rugged crags of the Rocky Mountains to the height of the Appalachians, the vaporous atmosphere of the Pacific would flow eastward far more freely than now, and meet that which, by the convectional action of cyclones, is frequently carried from the Atlantic Ocean and the Gulf of Mexico inland to the Mississippi Valley; then rain would be more abundant and the whole of the United States would have arable land.

To give a further idea of the effect of mountain systems on the climates of continents one needs only to reverse the conditions just mentioned; if the Appalachian Mountains were as high as the Rocky Mountains, and if they extended farther southward and bordered the Gulf of Mexico, then the Ohio River, the Mississippi, and the Missouri and their many tributaries would not exist, and the world's greatest granary would be a gray and nearly barren plain.

The specific heat of water is greater than that of almost any other substance. It requires ten times the quantity of heat to raise a pound of water  $1^{\circ}$  than it does to raise a pound of iron  $1^{\circ}$ . Solar rays penetrate the sea to a considerable depth; they are quite uniformly absorbed by the stratum penetrated. In consequence of these laws and conditions a vast quantity of heat is stored by the ocean in the Tropics and slowly given to the air as the ocean currents carry the warm water toward the poles. In this connection the writer would correct what he believes to be an exaggerated popular idea relative to the effect of the Gulf Stream on the climate of Europe. The North Atlantic circulation, flowing northward on the western side of the ocean (except a southward current from Davis Strait that chills Labrador and somewhat affects the temperature of the New England coast), and southward along the coast of Europe, is many times more effective in modifying climate than is the Gulf Stream. That the western part of Europe is warmer, more humid, and subject to less radical

changes in temperature than equal latitudes in North America, except on the Pacific coast, is due primarily to the great ocean that lies on the west of Europe. Without ocean currents of any description this body of water would give to the air that moves from it to Europe a more equable temperature than is possessed by the eastern part of the North American Continent. Continents, therefore, partake largely of marine climates on their western borders, and principally of continental climates on their eastern borders.

Climate affects the health, happiness, and well-being of people more than any other condition that goes to make up their environment. Within the broad confines of the United States there are many, but not all, shades and varieties of climate. One of the questions most frequently asked is: "Where shall I find a climate possessing both dryness and equability of temperature?" To this interrogatory reply must be made that the ideal climate as regards equability of temperature and absence of moisture does not exist in the United States, but that the nearest approach to it will be found in the great Southwest.

The temperature of the Southwest is not equable in the sense of having an extremely small daily range, but it possesses the quality of annual uniformity in a greater degree than will generally be found elsewhere, except on the seacoast, and there the humidity is great.

The most equable temperature on the globe will be found on the high table-lands and plateaus of the Tropics. Santa Fé de Bogota, in the United States of Columbia, has an average temperature of about 59° F. for all months of the year, and the range for the entire year is less than is often experienced in a single day in some parts of the middle latitudes. But while the ideal temperature may be found on the higher elevations of the Tropics, the rainfall is much greater and more continuous than in this country.

The temperature of a place depends chiefly on three conditions—latitude, elevation, and contiguity to large bodies of water. At sea level in the Tropics extreme conditions of heat and moisture produce very great physical discomfort. But even under the equator it is possible to escape the tropical heat of low levels by ascending from 4000 to 6000 feet. In the economy of nature there is a certain limit beyond which the two extremes, dryness and equability of temperature, can



not coexist; thus we may find a region so deficient in moisture as to satisfy the requirements of the case, but the very lack of moisture is a condition that facilitates radiation and thus contributes to great extremes of temperature. Regions may be found, as on the lower Nile, where there is a lack of rainfall coupled with a high and moderately uniform temperature. The mean winter temperature of Cairo, Egypt, is  $56^{\circ}$  F.; mean summer temperature,  $83^{\circ}$ ; a range from winter to summer of  $27^{\circ}$ . The mean winter temperature of Phoenix, Ariz., is  $52^{\circ}$ ; mean summer temperature,  $87^{\circ}$ ; a range of  $35^{\circ}$ . It is by no means difficult to find a counterpart of the far-famed Egyptian climate in the great Southwest.

The dryness of the air and the clearness of the sky are the conditions upon which daily ranges of temperature depend; the greater these, the greater the range of temperature from day to night. While a high summer temperature is characteristic of the Southwest and other portions of the Rocky Mountain Plateau, it is a fact that the sensation of heat as experienced by animal life there is not accurately measured by the ordinary thermometer. The sensation of temperature which we usually refer to the condition of the atmosphere depends not only on the temperature of the air, but also on its dryness and the velocity of the wind. The human organism, when perspiring freely, evaporates the moisture of its surface to the dry air of the interior arid regions, and thus lowers its temperature and prevents sunstroke, which, in the more humid regions from the Mississippi Valley eastward, occur in great number with the air temperature much less than obtains in the West.

The meteorological instrument that registers the temperature of the evaporation, and thus in some measure the actual heat felt by the human body, is the wet-bulb thermometer. The latter, as indicated by its name, is simply an ordinary mercurial thermometer whose bulb is wetted with water at the time of observation.

*Effect of climate on the races.*—Climate is the most potent of any factor in the environment of races. It is climate and soil, plus heredity and form of government, that produces either vigorous or weak peoples. In this respect it is a question if the United States does not possess a constant potential that, all other conditions being equal, places it in a class by itself.

Climate, soil, and good heredity may produce a race large

of stature and of great physical endurance, but unless such a people exist under a liberal form of government, in which public education is fostered and the arts and sciences taught, it is unable to employ its strength in those lucrative vocations that alone give a high per capita of wealth; and wealth means power. It is also weak in defending itself, either in war or in commerce, against a people of less numerical strength that is liberally educated, skilled, and humanely governed.

If one reads of the overthrow of political dynasties and the subversion of trade and commerce, it will occur to him that northmen have usually been conquerors. If we consider the invigorating effect of cold air and marked changes of temperature alone we might expect to find the strongest and most resourceful peoples inside of the Arctic Circle; and if we consider fruitfulness of soil alone we might reasonably expect to find the dominant peoples in the Tropics. But the fact is that the greatest human potentiality occurs somewhere between these two extremes. The boundaries can not be accurately determined by the naming of certain parallels of latitude, but a close approximation is made to the truth in the statement that the most vigorous people physically and the most resourceful mentally will be found in the most northerly regions that will produce not simply cereal crops, but an abundance of them.

The sweep of the cold wave, as it is known in the United States, is quite distinctly North American. Nowhere else on fertile plains, unless it be in Russia, does the temperature show such wide oscillation within such short periods of time, nor do the icy blasts sweep over such a broad area. It is probable that much of the physical and the intellectual energies that have caused the United States to excel in agriculture, in manufacturing, and in commerce, were produced by the invigorating effect of the cold, dry, highly electrified air of the North American cold wave. The anticyclonic systems of air that constitute cold waves have a marked downward component of motion. This motion brings from a considerable altitude to the surface of the earth some of the high electrical potential of the upper air, which is strongly stimulating to man and to other forms of animal life. These cold north winds have a much greater specific gravity than warm and humid winds, and this condition, added to the force with which they come, scatter and diffuse the befouled air near the surface of

the earth. Enough has been said to indicate that climate is nearly as important a part of the environment of animal life as it is of the vegetable existence, and that a wide range of annual temperature, if it be not so great as to limit the production of cereal crops, favors the development of strong races of men.

*Change of climate.*—Notwithstanding the popular notion to the contrary, there is reason to believe that there has been no appreciable change in the climate of any large area within the period covered by authentic history. Changes in the surface of the earth may be noted within the lifetime of an individual, that are thought to prove that a change of climate has taken place, when the alterations may be due to the persistent action of freezing, thawing, rainfall, and flood. Great changes have occurred during geologic periods, but it is the opinion of the writer that they take place so slowly that thousands of years must elapse before their effect is measurable.

*Effect of forests on climate.*—Extremes of temperature, both heat and cold, are slightly less over forests than over open regions, but the most important effect of forests on climate is the economic conservation of precipitation, diminishing the intensity of floods by restricting the flow-off, and by shading the snow deposited during the winter from the increasing sun of spring and early summer. More moisture is absorbed by the soil when it is covered by forest than when it is cleared of its forest cover, and it follows that deforestation, if extensive, may diminish the supply of springs and streams.

Investigations in Germany and in India seem to indicate that there is an appreciable increase in rainfall as a result of reforestation. In general, forest may be looked upon as the effect rather than the cause of rainfall.

*Climate and animals.*—The geographic distribution of animals is doubtless the outcome of definite laws—laws that stand in close relation with the past history of the earth through a large portion of geological time. What those laws are forms a subject of great importance in studies of evolution, a subject, it may be remarked, entirely too great to be adequately treated in the present connection. Naturalists are generally of the opinion that all animals have been produced from those that preceded them by some slow process of transmutation or development, and that this modification of animal forms took place very slowly, as evidenced by the fact that the historical

period of nearly 4,000 years has hardly produced any perceptible change in a single species. That marked changes in the climate of the earth have occurred during the remote past there can be no doubt, and that those changes left a marked impress upon the fauna of the globe there can also be no manner of doubt. The great northern ice sheet and the accompanying cold of the glacial period, if it did not cause the extermination of the receding fauna, doubtless led to its migration to more congenial climates.

The part played in the faunal distribution of the globe by the present climate seems to be indirect rather than direct, although there are many facts which seem to point to a direct relation. While it is true that the fur-bearing animals of the frozen north are generally to be found in arctic regions, yet they send their representatives far into the temperate latitudes, and indeed into the borders of the regions inhabited by the more exclusively tropical species. On the other hand, the tiger, whose home is naturally associated with the hot districts of India and the Indian Archipelago is equally at home in the elevated regions of the Caucasus and the Himalayas, where his footprints are not infrequently found impressed in fields of snow. Other groups of animals are more limited in their migrations. Some are so closely adapted to an arboreal life that they never stray far beyond the limits of forest vegetation, while others are so tolerant of climatic change that the limit of their possible range is conditioned only by the character and quantity of the food supply and the interposition of impassable physical barriers.

*Climate and plants.*—The factors necessary to the development of plant life are light, heat, soil, and moisture. The ideal conditions as regards these essentials do not usually obtain, or, if they do, multitudes of plants seek to take possession of the region, so that there is a continuous struggle for existence in which many more plants fail than succeed.

The climatic factors, heat and moisture, are combined in several ways in different parts of the globe, and these combinations give widely different vegetation; thus a maximum of heat and a minimum of water give desert conditions where only specially adapted plants can exist. If, on the other hand, a maximum of heat is combined with a maximum of water, the result will be vegetation such as exists only in the rainy tropics. The possible combinations of the two climatic fac-

tors are very numerous, as are also those of soil and the effects of animal life and human agencies. Yet the vegetation of the globe is susceptible of a fairly definite classification. Following Humbolt, and adopting such terms as express in a general manner the vegetation characteristic of each zone, we have the following classification:

Zones of—	Average temperature.
	°
1. Palms and bananas.....	78-82
2. Tree-ferns and figs.....	73-78
3. Myrtles and laurels.....	68-73
4. Evergreens.....	60-68
5. Deciduous trees.....	48-60
6. Conifers.....	40-48
7. Lichens, saxifrages, and dwarf shrubs.....	32-40
8. Lichens and mosses.....	32 and below.

While in a general way these zones stretch around the world in wavy belts, somewhat as do the isotherms, similar belts may be found encircling mountain peaks and chains with increasing altitude above sea level. Indeed, it is possible to pass successively from tropic to arctic vegetation on a single mountain peak in the Tropics.

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Bulletin No. 35.—W. B. No. 322.

U. S. DEPARTMENT OF AGRICULTURE,  
= WEATHER BUREAU.

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LONG-RANGE WEATHER FORECASTS.

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Prepared under direction of WILLIS L. MOORE, Chief U. S. Weather Bureau,

BY

E. B. GARRIOTT,  
PROFESSOR OF METEOROLOGY.

WASHINGTON:  
GOVERNMENT PRINTING OFFICE.  
1904.

Sc 769.115

# LETTER OF TRANSMITTAL.

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U. S. DEPARTMENT OF AGRICULTURE,  
WEATHER BUREAU,  
*Washington, D. C., October 28, 1904.*

Hon. JAMES WILSON,  
*Secretary of Agriculture, Washington, D. C.*

SIR: I have the honor to transmit herewith a paper on the subject of long-range forecasts, by E. B. Garriott, professor of meteorology, and to recommend its publication as a bulletin of the Weather Bureau. It includes a valuable paper by Prof. C. M. Woodward, of Washington University.

The first chapter, by Professor Garriott, presents a verification of the work of the most prominent of the so-called long-range weather forecasters in the United States that shows conclusively the fallacy of their predictions. The second chapter, by Professor Woodward, shows the impossibility of basing weather predictions on planetary influences. This chapter was published by Professor Woodward in 1875 in Ware's Valley Monthly, and Mr. Tice, whose theory of planetary equinoxes is discussed and refuted, was the predecessor of a long-range weather forecaster who is now operating in St. Louis, Mo.

The remainder of the paper is devoted largely to the discussion of the subject by many of the leading meteorologists of the world. It reviews the literature of long-range weather forecasts, and quotes the opinions of leading scientists regarding the practicability of long-range work. It refers to theories regarding weather periodicities depending upon lunar and planetary influences; summarizes results obtained by comparisons of maximum and minimum sun-spot periods with the phenomena of the earth's atmosphere; states that the next advance in meteorological science must result from extensive research in solar physics and terrestrial magnetism and comparison of solar and terrestrial phenomena; assumes that advances in the period and accuracy of the official weather forecasts depend largely upon a study of atmospheric pressure over great areas, and a determination of the influences that occasion normal and abnormal distribution of the greater atmospheric areas.

The success of the United States Weather Bureau in making conservative forecasts of the weather two or three days in advance has created the hope in the minds of the people that it may be possible to foresee the character of the weather for the coming month or season. All scientific men know that at present it is impossible to gratify this wish, and the Government experts so inform all those who make inquiry. But the mistaken investigator of little knowledge, the pseudo scientist and the astrologer, see their opportunity and at once

step into the breach and sell spurious long-range forecasts to a public rendered credulous by the success of the Government scientists. The abuse of the public confidence has become so great that I have thought it justifiable to present to the reader indisputable evidence of the injurious character of monthly or seasonal forecasts.

It is the opinion of the leading meteorologists of the world that public interests are injured by the publication of so-called long-range weather forecasts, especially by such predictions as relate to severe storms, floods, droughts, and other atmospheric disturbances of a dangerous or damaging character. The publication of monthly forecasts has reached such proportions that it is deemed advisable to inform the public as to their harmful character. Some monthly forecasters may be honest, and may, in their ignorance, attach undue importance to storms that accidentally coincide in time of occurrence with certain relative positions of the moon, or with periods of increase or decrease in sun spots, or apparent variations in the solar intensity. To men of this class the occurrence of a storm within the broad area of the United States on or near the day for which they have predicted a storm confirms, in their minds, the value of their system of prediction. They may believe that they have discovered a physical law or a meteorological principle that has not been revealed to astronomers, meteorologists, or any other class of scientific investigators, but the publication of predictions that, by reason of their inaccuracy are positively injurious to agricultural, commercial, and other industrial interests casts a doubt upon the honesty of their makers.

As a result of my personal verification of the work of long-range weather forecasters, some of whom have so far gained the confidence of the rural press as to receive liberal compensation for their prediction, I am led to the conclusion that these forecasters do positive injury to the public at large. It is to be regretted that so many newspapers not only give space to these harmful predictions, but actually pay for them. Forecasts of this description may properly be classed with advertisements of quack medicines—they are both harmful in the extreme.

I hope the time will come when it will be possible to forecast the weather for coming seasons, to specify in what respect the coming month or season will conform to or depart from the weather that is common to the month or season, but that time has not yet arrived, and I believe that we will serve the public interests by teaching the people the limitations of weather forecasting, and by warning them against imposition.

Very respectfully,

WILLIS L. MOORE,  
*Chief United States Weather Bureau.*

Approved.

JAMES WILSON,  
*Secretary.*

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## VERIFICATION OF LONG-RANGE WEATHER FORECASTS.

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The proof of the forecast is in its verification. Measured by this standard, long-range weather forecasts have an experimental value only, a value that does not justify their employment in the actual work of forecasting for specified dates and places.

Meteorologists who have conceived theories for long-range forecasting, or who have tested theories advanced by others, have applied to the theories the test of facts that are presented by meteorological records, and the results have been negative. Men who issue fake forecasts have adopted an opposite method. They have carefully ignored and concealed facts and have depended upon advertisements of occasional successes that will inevitably occur in any system of chance, and their success may be measured by the extent to which they can impose upon the credulous and the ignorant.

As a rule, it is impossible to subject the rambling and indefinite statements of the long-range weather forecaster to a verification. In the summer of 1903, however, one of these forecasters was induced to submit to the Weather Bureau some forecasts for verification. The forecasts consisted of an enumeration of certain dates around which "storms would cluster and develop great intensity." The periods, or dates, of maximum storm force as forecast and the actual weather conditions that appeared on the dates were as follows:

*August 11, 1903.*—On this date there were no storms in any part of the United States, and no extraordinary weather conditions were manifested at any point within the region of observation, except that a tropical disturbance of small diameter was apparently moving westward south of Jamaica, West Indies. As the forecast did not specify in what part of the Northern Hemisphere the storms would reach their maximum intensity, it can not be considered that the occurrence of this storm in any way verified the forecast.

*August 24, 1903.*—On this date no evidence could be discovered of an increase of storm force, the usual stagnant summer conditions prevailing in all parts of the United States.

*September 7, 1903.*—On this date the weather conditions were not unusual; there were no storms of marked energy in any part of the country. A disturbance covered the northern Rocky Mountain region and the upper Missouri Valley, but it moved northeastward and did

not in any way affect the region to the eastward. There was nothing unusual in the disturbance above mentioned. A storm of considerable energy developed in the vicinity of the Bahamas on September 10 and persisted in the vicinity of the Gulf region until the 15th. No mention of this disturbance was made in the forecast.

*September 21, 1903.*—On this date, likewise, the usual weather conditions prevailed in all parts of the region of observation.

*October 6, 1903.*—On this date a depression of considerable magnitude covered the eastern slope of the Rocky Mountains. It moved eastward and developed into a severe storm on the Atlantic coast on the 9th and 10th, three days after the date set by the forecaster.

*October 19, 1903.*—On this date the usual October weather prevailed in all parts of the United States. There was not the slightest evidence of increased storm energy on this date.

This is a plain statement of the weather conditions experienced on the dates when, according to the forecasts, the most severe storms of recent years were to occur. Let us quote of the forecasts:

Clustering around September 7 and 21, October 5 and 20 will come some of the most severe storms of recent years. These will be so general all around the earth that I advise all to be on guard near the dates named. Storms miss ninety-nine out of one hundred places, but you will at least read of tornadoes, hurricanes, cloud-bursts, electrical storms, seismic disturbances in nearly all sections where these sometimes occur.

Considerable time has already been devoted to an examination of forecasts of this character, and the results thus far obtained show that the forecasters possess no knowledge that would justify them in the making of predictions.

To a long-range forecaster the occurrence of a thunderstorm or an electrical disturbance in some remote corner of the globe during one of his "storm periods" will justify his forecasts.

The matter of verifying the forecasts of this long-range forecaster was again taken up during the present year, the forecasts used being those that appeared in the public press. It was found that one element only was stated in language that would permit a verification—the temperature.

With the approval of the forecaster the forecasts that applied to the region of the ninetieth meridian were alone considered, and these were verified by the records of the Weather Bureau office at Springfield, Ill. The verifications showed that, considering the law of chance, the times when the actual temperature conformed, even in a general way, to the forecasts were surprisingly few. In fact, the forecasts of warm and cold waves, if reversed, would result in a higher percentage of verification.

Forecasts of this character can be of no value to agricultural, commercial, or maritime interests. On the contrary they are misleading, and if given credence are calculated to result in positive injury. Farmers, merchants, and mariners who keep pace with modern progress do not give credence to this class of forecasts. A long-range forecaster who receives remuneration for his work is simply catering to a class of readers who are deficient in a knowledge of the present status of popular science.

There is another long-range weather forecaster who draws his support from the American public who does not depart in any essential manner from the methods employed by the one above referred to. His statements are based upon a consideration of the moon's path with reference to the ecliptic and the equator, the phases of the moon, disturbing causes due to movements and positions of the planets, etc.; in fact, a conglomerate gathering together of all imaginary and obsolete notions regarding weather causes that are calculated to mystify credulous and uninformed people. He predicts the general character of a month with a consciousness that the forecast will be verified in at least some part of a great unspecified area. He then outlines "storm periods," with intervals of two or three days, which are covered by a margin that is claimed for verification purposes, and verifications are claimed if storms occur during the periods or in the intervals in any part of the United States, and, at times, in the Northern Hemisphere. This system of forecasts and verifications admits of no failures. So much for his regular forecasts. Let us now examine some of his special, emphasized predictions:

In the early part of April, 1904, a tornado and severe storms were scheduled in various western papers over the name of this forecaster to appear "right after April 17." The storms failed to materialize in the United States during the period specified. Reports from remote parts of the Northern Hemisphere have not, however, been received, so it is possible that a justification of the forecast will be claimed. Aside from platitudes regarding average weather conditions that prevail in April, he announced that—

One of the most decided, and perhaps violent, storm periods of the month extends from about the 25th to the 29th.

In the United States the period was a quiet one, and the disturbances that appeared (and one or more surely would appear within the area of the United States during the period specified) were not attended by "very general and violent storms, destructive hailstorms, and abnormal downpours of rain," which, according to the detailed forecast, should have been experienced.

His forecast statement for May, 1904, ends as follows:

The fifth storm period will be central on the 29th and there will be violent disturbance. Watch the barometer, and if you have a trembling wife and children clinging to you for protection provide some place of safety in which to resort in case of danger.

Is it possible to soar to greater heights of nonsense? In what particular continent or country will the storm period be central on the 29th? Is the entire population of the United States, or of the world, expected to dig cellars or caves of shelter in anticipation of a possible occurrence of a tornado whose path of destructive violence would not cover an area represented on a large map by a mark one-half an inch in length made with a sharp pencil? Is it possible that a man who issues such totally unwarranted, sensational, and harmful forecasts is seriously considered by the intelligent portion of the American public? I regret to say that he and others of his kind have a considerable constituency.

## THE PLANETARY EQUINOXES—AN EXAMINATION OF MR. TICE'S THEORY.

[By Prof. C. M. WOODWARD, of Washington University.]

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I have been so frequently asked to explain the astronomical grounds on which Mr. Tice's meteorological predictions rest, that I have thought it worth while to put the following explanations, or refutations, on paper. The partial fulfillment of some of his predictions has given them a notoriety which, coupled with the publication of a volume purporting to give a full account of every phenomenon in meteorology, may justify me, or serve as my excuse, in their investigation.

A glance at Mr. John H. Tice's *Elements of Meteorology* will convince anyone that Mr. Tice is a conscientious, painstaking, and enthusiastic student of meteorology. The record he gives of his labors does not seem to be overstated, and though he is ambitious of a scientific reputation he is not intentionally dishonest or unfair. This much is due at the start to one who has zealously devoted a large part of a long life to scientific subjects. It is, however, with severe disappointment and positive pain that, on a more careful examination of his little work, I discover the author to be lacking in many of the qualifications of a scientific writer. While, therefore, I recognize to the fullest extent his zeal and honesty, it becomes my duty in reviewing the facts and arguments upon which his theory rests to point out grave errors in mathematics and astronomy, and methods of reasoning, to say the least, novel and unsatisfactory. Perhaps, after all, it would be better and kinder to quietly lay Mr. Tice's work on the shelf and say nothing about it. But such a course would be unsatisfactory to all. If the foundations of his theory are well laid, and his conclusions are logically reached, he has certainly made the greatest physical discovery of the century (which is, I think, what he claims), and he richly deserves the strong language of praise and commendation which has greeted his little volume. On the other hand, if Mr. Tice has built upon the sand, and his theory is but a castle of straw

which falls under the first blow, it is due to science, and above all it is due to the friends and patrons of Mr. Tice, that the exact truth be told.

It should be premised that astronomers and physicists have during the last half century been carefully observing and tabulating all sorts of phenomena previously considered purely fortuitous. Schwabe's discovery of the regular recurrence of sun-spot periods was the first fruit of such systematic effort. Careful analysis of sun-spot observations since 1826 shows a period of 11.11 years between two successive times of maximum frequency. Next it was found that exactly the same period holds good for special magnetic disturbances or storms, and that the times of maximum and minimum sun-spot frequency agree with the times of maximum and minimum magnetic disturbance. These complete coincidences are what Mr. Tice calls "incontestable facts." Next it was found by observers in the East and West Indies that the years in which the sun spots were the most frequent, and the earth was electrically most excited, were also the years in which hurricanes were the most terrible and most numerous.<sup>b</sup> Various other phenomena seemed to be periodic, agreeing closely with the above.

Such striking coincidences did not fail to suggest a common cause, or, at least, the relation of cause and effect. Jupiter makes a complete revolution in his orbit in 11.86 of our years, a period only slightly larger than that mentioned above. This coincidence and some others affecting the planets have been much discussed, and I can not better show how they have struck the minds of astronomers than by quoting a few words from Mr. Richard A. Proctor's work on *The Sun*:

As respects the sequent series of researches by which Messrs. De La Rue, Stewart, and Loewy have endeavored to estimate the influence of the planets upon solar spots, it is to be remarked that the evidence adduced seems as yet not wholly decisive. They believe that it has been rendered probable that Venus exerts a special influence on the solar spots, and that the conjunctions of the planets also affect importantly the condition of the solar photosphere. There is room, in my judgment, for some doubt as to the justice of either conclusion. It should not be forgotten that the planetary system represents so many periodic relations as to render it almost certain that any periodic changes in the sun's condition may be associated statistically with some period of planetary motion—siderial, synodical, nodical, or otherwise. There is a remark toward the close of Carrington's volume on the solar spots which bears very significantly on this subject. After exhibiting the relation between the phenomena of solar spots, as tabulated by Professor Wolf, and Jupiter's variations of distance, he says that "from the year 1870 there is a very fair agreement between the maxima of frequency and maxima of Jupiter's radius vector, and between minima and minima;" but "in the two periods which precede that date

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[<sup>b</sup>Recent studies show no relation between sun spots and hurricanes.—Note by editor.]

there appears to be a total disagreement." "It is important," he then adds, "to see before us an instance in which *eight consecutive cases of general but imperfect agreement between the variation of two physical phenomena are shown to be insufficient to base any conclusions upon*, at the same time that they powerfully stimulate further inquiry with the view of ascertaining whether the discrepancy may admit of future explanation. I would by no means be understood to imply, however, that I regard the conclusions of Messrs. De La Rue, Stewart, and Loewy respecting the influences exerted by the planets on the solar phenomena as inadmissible. On the contrary, I regard them as, on the whole, the most probable yet advanced. Based as they are on observed facts and on statistical relations, they are worthy of the most attentive consideration. They do not seem to me, however, to be by any means *demonstrated*, nor are they so regarded (it is proper to add) by their propounders."

I have quoted fully for two reasons: First, to show that as far as Jupiter is concerned, the main coincidence seems to be between the times of minimum spot frequency and Jupiter's perihelion, and between the times of maximum spot frequency and his aphelion; and, secondly, for the purpose of showing how cautious scientific men are about assuming things to be demonstrated.

Now, of course the most of this was well known to Mr. Tice when he began looking for the "great cycle."<sup>a</sup> He had observed that some phenomena were periodic, and he thought that all might be so, and he hoped by establishing a great meteorological cycle he would have the key for explaining all atmospheric phenomena. So great was his anxiety to secure exact coincidence between the periods I have mentioned, that in spite of some very sensible remarks against the practice of obliterating all individual phenomena by resorting to very general averages, he, according to his own confession, "lumped" the phenomena of sun spots, hurricanes, and magnetic storms with others of less frequency, and succeeded in getting an *average* of 11.83 years. This differs from Jupiter's period but about 0.03 of a year; this he jumped, and adopted Jupiter's period of revolution as the "great cycle." It seems as though this forcing process would be suicidal to any theorizer, for as the period of sun-spot phenomena is beyond all question almost exactly 11.1 years, Mr. Tice's "great cycle" is in excess of that fully three-fourths of a year, an amount which would change exact agreement into total disagreement in five or six periods; and this is just the fate of Mr. Tice's cycle. He seems not to have remembered that finding the average of several unequal periods does not after all make those periods equal.

The point Mr. Tice reaches is that all atmospheric phenomena are

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<sup>a</sup> Although he says: "I *projected* the hypothesis that Jupiter in some unknown way was the cause of the perturbations" (p. 11), I should say here that in all the quotations I make from Professor Tice's book I shall follow his exact language, including punctuation and the use of capitals. The italics, however, will be mine.



produced by planetary equinoxes. (P. 130.) His minor premises are thus stated:

There are two facts that are undeniable; which are not only necessary to establish our theory but they render it incontestable. The first fact is that the Earth and the Atmosphere at the equinoxes always undergo an intense electric disturbance; and the second is that the telluric disturbance extends to and affects the sun, [p. 18] and through it the other planets.

It may be true that the earth undergoes an intense electrical excitement at each equinox. It is generally supposed that with the change of seasons which accompanies the passage of the sun from the north of the equator to the south, or the reverse, the weather is much unsettled. The swinging of the periodic winds, the shifting of the zone of calms, and the high atmospheric tides which must result from the sun's being in the plane of the equator, make this seem quite reasonable and in harmony with observation. But the second "undeniable fact," that the "telluric disturbances extend to and affect the sun," will, I fear, be seriously called in question if it is meant that they *sensibly* affect the sun. In proof of this "fact"—and it is the proof he offers—Mr. Tice says that "it is established by observation that sun spots have a marked maximum during our equinoxes." I do not find this to be true. I have carefully examined the elaborate panoramic plates of Mr. Carrington, in which he gives the solar spots observed by himself during the nine years from 1853 to 1862, *and I find no such maxima in the equinoctial months*, nor, indeed, in any other months. Of course, I am sorry to deny an undeniable fact, especially one so essential to Mr. Tice's argument; but I find no evidence whatever for supposing that the equinoctial storms of our earth sensibly affect the sun.

Having proved the influence of the earth's equinoxes, he wishes to show the immense influence of the equinoxes of Jupiter. Hence the adoption of Jupiter's year as the "great cycle" is all important to his demonstration, and as it is really a point of considerable interest I will ask you to examine carefully this table of dates:

I. Dates of maximum sun-spot frequency.	II. Dates of Jupiter's aphelion.	III. Mr. Tice's major equi- noxes of Jupiter.	IV. Mr. Tice's minor equi- noxes of Jupiter.
1816.8	1815.20	1812.44	1818.37
1829.5	1827.16	1824.30	1830.23
1837.2	1839.12	1836.16	1842.09
1846.6	1850.98	1848.02	1853.95
1860.2	1862.94	1859.88	1865.81
1871.6	1874.80	1871.74	1877.67

Column I gives the dates of maximum sun-spot frequency in which all observers substantially agree. Column II gives the dates of Jupi-

ter's aphelion. Columns III and IV contain the dates of what Mr. Tice calls the "major" and "minor" equinoxes of Jupiter. As to the determination of these dates I shall have something to say further on.

It is easily seen that neither of the last three columns agrees very closely with the first. This is due, as was said above, to the difference between Jupiter's period and the sun-spot period. The dates in the last three columns regularly increase by 11.86 years, while those in the first are irregular, with an average interval of about eleven years. It is incredible that anyone should consider the coincidence of either one of the last three with the first as "demonstrated." Mr. Tice gives, no doubt unintentionally, a false impression in regard to the dates of sun-spot frequency. He heads Column I of this table "Average maxima," and from his remarks one would conclude that each was the *average* of two dates, agreeing respectively more closely with Columns III and IV. Now, in the first place, the dates in the first column are not averages at all; they are the years when sun spots, magnetic storms, and cyclones were actually most numerous.<sup>a</sup>

An examination of Professor Wolf's analysis of Schwabe's observations shows that Mr. Tice should not have used the heading "*Average maxima*."

Moreover, the dates of minimum sun-spot frequency are very nearly midway between those of maximum. So that, if Mr. Tice's "major equinox" coincides with the time of the maximum his "minor equinox," instead of being coincident with a second maximum, must nearly coincide with the absolute minimum.

Of course we can not enter more fully into these interesting subjects. Many volumes have been written upon them, and they still claim the attention of astronomers and physicists.<sup>b</sup>

Nothing is clearer than that our author has been guilty of a credulity unbecoming a scientific man in assuming it to be *proved* that Jupiter is the main cause of the solar period, and building upon such a very insecure foundation. He says:

For ourselves, without any hesitation and qualification, we accept it no longer as a theory, but as demonstrated and verified truth that not only the occurrences of Jupiter's equinoxes but those of the other planets are the causes of the disturbances in the sun, and consequently *in the whole solar system*. (P. 75.)

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<sup>a</sup> When Professor Woodward read this lecture in the hall of Washington University he exhibited a graphical representation of the occurrence of sun spots. The curve of frequency ran sharply to a maximum once during every eleven years like irregular teeth in a saw—EDITOR.

<sup>b</sup> In a recent address Professor Huxley discusses the relation of planets to the sun spots, and while he points out some coincidences in the case of the nearer planets he makes no mention of Jupiter. (See Popular Science Monthly for November, 1875.)

It is worthy of remark in connection with this statement of a firm conviction that Jupiter is the cause of the periodic phenomena of sun spots, that the maximum of spots occurs, according to the table we just examined, when Jupiter is near his aphelion, or greatest distance from the sun. Were he the cause of the spots (of which Mr. Tice has not the slightest doubt) we should expect quite the reverse to be true, as it is not consonant with our experience that a physical cause has the greater effect the farther it is away.

We come now to the most remarkable features of Mr. Tice's book, viz, his theory of planetary equinoxes and his methods of determining their dates. His theory is given above, in his own words. Let us examine his demonstration.

But first I must remind you of a little elementary astronomy. The axes of the sun and the planets preserve almost exactly their directions in space in spite of their revolutions about each other. The different axes are by no means parallel, but each points continuously to the same spot on the infinite celestial sphere. In this statement I ignore the effect of precession and nutation observed in the case of every member of the solar system, because the annual changes are so very small. All are familiar with the fact that the plane of the earth's equator, the "equinoctial," lies half the year on one side the sun and half the year on the other as the earth moves around its orbit, and that twice in the year this plane passes through the sun. At such times the sun appears to us to be on the celestial equator, or "on the line," and as the sun is visible from one pole to the other of the earth just twelve hours by day and invisible just twelve hours by night, these two positions of the earth are called its "equinoxes." A similar statement may be made for each planet. Hence each planet passes two equinoxes during each of its years. When on one side of the sun, say north of it, the planet's south pole is specially exposed to solar influence, and when south of the sun the north pole is similarly exposed. The importance of these changes in producing "seasons" obviously depends upon the size of the angle which the plane of the planet's equator makes with the plane of its path.

But there is another inclined plane which is of first importance in stating Mr. Tice's theory. The sun at the center of the system revolves upon its own axis, and although his axis is nearly perpendicular to the planes of the planets' orbits, it is in no case exactly so. The consequence of this obliquity of the solar axis is that each planet is during one-half of the year exposed to one pole of the sun and during the other half to the other. In the case of the earth, we get our greatest view of the south pole of the sun March 6 and our best view of the north pole September 5. On these dates the earth is at its greatest distances south and north of the plane of the sun's equator. You will observe the degree of coincidence between these

dates and those of the equinoxes, March 22 and September 21. The difference, however, is not a constant quantity.<sup>a</sup>

Now, Mr. Tice regards the sun and each one of the planets as an immense magnet, such as would be formed by passing a current of electricity through a coil of wire through the center of which, in a line perpendicular to its plane, there is a bar of soft iron. Of course, such a magnet has a north pole and a south pole, depending upon the direction in which the current flows. He assumes in all his reasonings that this current coincides with the equatorial belt and that the magnetic axis coincides with the axis of rotation. To be sure, he refers to the lack of coincidence of these axes in the case of the earth, and suggests that the like may be true of the sun, but elsewhere he assumes their agreement.<sup>b</sup>

It is obvious that two such magnets would in general influence each other, like poles repelling and unlike poles attracting each other, and in the case of moving magnets that the strength of such influence would vary. Our author thus refers to the earth's alternate exposure to the poles of the sun:

In consequence of the inclination of the earth's axis to the plane of the Ecliptic, the South magnetic pole of the Sun at one Equinox, and his North magnetic pole at the other, are pointed more directly toward the earth than at any other points on its orbit. (P. 15.)

You will remember that I showed you that the earth was at its points of greatest distance north and south of the sun's equator only about sixteen days before the equinoxes. In the last quotation you will notice that it is assumed that these points coincide. Then he assumes that a like coincidence exists in the case of every planet, and thus proceeds to give the source of the influence of such an equinox.

These existing causes (which not only arouse the planets to greater activity, *but influence the sun himself* to modify, diversify and vary his energy,) are the equinoxes by which a planet alternately renews its electric vigor; now by the North, and anon by the South magnetic pole of the Sun, thus alternately imbibing electric energies that, we have good reason for believing, differ in many essential properties. (P. 95.)

You will be surprised to know that after making the above statements of the source of the special influence of a planetary equinox, he nowhere mentions the amount of this alternate exposure of a planet to

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<sup>a</sup> Mr. Tice gives the difference between these dates as ten days, but he evidently follows Herschel, who does not give the later and more accurate data.

<sup>b</sup> This suggestion is made by Mr. Tice, in these words:

"Since it is probable that the magnetic poles of the Sun, like those of the Earth, do not coincide with the poles of his axial rotation; hence, if this is the case, each solar pole is equivalent to a moving magnet to all the planets, and therefore a powerful generator of electricity in them" (p. 15). He says (p. 16): "All rotating bodies, from a disc to a sphere, generate electric currents at right angles to the axis of rotation."

the poles of the sun, except in the case of the earth. He does not seem to know that it is not the same for all planets, and that it has nothing whatever to do with the inclination of the planets' axes to the planes of their orbits. The inclination of the axis alone determines the amount of seasonal changes in a planet, but the amount of change to and from the poles of the sun depends solely on the inclination of the planet's orbit to the plane of the solar equator. Now, astronomers have discovered no law pervading the obliquities of the axes of the various planets. Nothing is known of the direction of the axis of Mercury. Some suppose that the axis of Venus makes an angle of only  $15^\circ$  with the plane of its orbit. The seasonal changes in Mars are slightly greater than in the case of the earth, and the same is true of Saturn, so far as mere obliquity is concerned. In Jupiter seasonal changes are hardly noticeable. It is well known that the case is quite different with the inclination of their orbits to the plane of the sun's equator. This increases as the distance of the several planets from the sun increases. Thus, the inclination of Mercury's orbit is  $0^\circ 19' 51''$ , and that of Neptune  $9^\circ 6' 51''$ . The only deviation from actual progression is in the case of the asteroids. From this we see that, in the case of Mercury, variation in exposure to the sun's poles amounts practically to nothing. Should there be a planet interior to Mercury—i. e., should Mr. Tice's Vulcan really exist—it is highly probable that the inclination of its orbit would be less even than that of Mercury. The inclination of Jupiter's orbit is considerable—somewhere near  $8^\circ$ —which I know will delight Mr. Tice, for he evidently overlooked this law and in some confused way has substituted for it the inclination of its axis to its orbit  $3^\circ$ . (See p. 19.)

From this it is evident that though Mr. Tice's suggestion of a solar magnet is not devoid of interest, he completely fails to follow the idea consistently through.<sup>a</sup>

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<sup>a</sup> It is easy to see that he should have determined when the axes of a planet and the sun were in the same plane, which is the case twice during each orbital revolution. For instance, the axes of the earth and sun are in the same plane July 8 and January 6. At the former date the north poles are most turned toward each other and at the latter the south poles. I must forego any discussion of Mr. Tice's views of physical astronomy. They are vague, inconsistent, and extravagant, and have little to do with meteorology. It will, however, be interesting to cite a few of his observations:

"Electric repulsion and not centrifugal force—as the mechanical theorists suppose—has given the form of oblate spheroids to all planets." (See p. 16.)

"We predict that when science has so far advanced that it can and will observe the phenomena resulting from what are now supposed to be mechanical influences, it will be ascertained that they are *not mechanical but dynamic*, and are produced by electric induction, repulsion, and attraction." (P. 19.)

"The influence exerted by a planet is entirely electric." (P. 13.)

He evidently does not believe in gravitation as a force distinct from electricity, and discards mechanics entirely, for dynamics with Mr. Tice means electricity.

But Mr. Tice endeavors to give us another reason for the potency of a planetary equinox, though it be at the expense of elementary geometry:

Astronomy establishes two points, namely, that at the equinoxes the Earth's Equator has its greatest obliquity to that of the Sun; and that at or near the solstices it has its least, since the plane of solar rotation then passes through the Earth. Electric laws exact that under such conditions, electric excitement should be at its maximum at the equinoxes and at its minimum at the solstices, and observation has confirmed that the facts correspond with the obvious deductions of Reason. (P. 17.)

This is stated a little differently on page 16:

Now from the inclination, and from the direction of the inclination of the sun's axis of rotation to the plane of the Ecliptic, and from the inclination of the Earth's axis of rotation to the plane of its orbit, it follows that the plane (equator) of the Sun's rotation, and that of the Earth make their greatest angle with each other at the equinoxes.

Similar statements are made on pages 19 and 72, except that there he does not limit them to the earth, but includes the planets generally, thus assuming that in every case the plane of the sun's equator passes through the planet at its solstices.

Unfortunately astronomy does not establish these two points, and, as far as this count is concerned, "electric laws exact" *nothing whatever*. The deductions of Mr. Tice's reason do not seem to be perfectly "obvious." The simple fact is, as every schoolboy in astronomy knows, the plane of the earth's equator makes with the plane of the sun's equator an *unvarying angle throughout the whole year*. There is positively no maximum and no minimum. This second argument, then, absolutely fails, and his demonstration must rest on the argument (lame as it is) of polar exposure.

I confess I am in great doubt as to what Mr. Tice really means by this second argument. It seems as though he must have deceived himself as to the definition of the angle between the two planes, and that this second reason is only an attempt to restate the first one. On page 72, however, I find them given as two separate reasons. Mr. Tice is either unfortunate in the manner of expressing himself, or in his mathematical training, and either way it is unfortunate for his theory.

Having, as he thinks, established the truth of his electro-equinoctial theory, Mr. Tice is of course anxious to know when these equinoxes actually occur.

When I was *satisfied* that the equinoxes of Jupiter were the causes of the two marked periods of disturbances in his year, I felt disappointed and discouraged when I found the books silent on this now to me vital point, because it was the turning point—either to disprove or confirm the projected theory. (P. 23.)

Astronomy is silent as to planetary equinoxes; those of the earth excepted. (Ibid.)



Behold how easily the man was satisfied of the truth of his theory of the equinoxes even before he went on his fruitless search for the dates of those puissant epochs. We can not help regretting Mr. Tice's limited opportunities for consulting astronomical data, for the dates of the equinoxes of Mars and Saturn are well known, as are probably those of Jupiter. Great uncertainty attends the data respecting Venus, while nothing is known as to the equinoxes of Mercury, Uranus, and Neptune. (The satellites of the last two suggest the positions of the equatorial planes.) As for Vulcan, as he is chiefly the creation of Mr. Tice's own brain, I shall not deny his right to assign him his equinoxes. What, then, does Mr. Tice do? The quotations already made clearly show the assumption that the equinoxes of a planet occur when it is at its greatest distances north and south of the plane of the solar equator. Consistency demands that he should calculate (as is easily done) when the several planets are at these points and call such positions equinoctial points. Does he do this? Not at all. First, he tried to reason it out in this way, and it carries him in an entirely new direction:

The first thing was to establish the solstitial points, upon which the books are equally as silent as upon the equinoctial, but as *telluric analogy* had served my purposes well so far, I relied upon it to furnish me both the solstitial and equinoctial points. On the Earth's orbit I found the *perihelion* and *aphelion* points closely coincide with the solstitial points. *I hence inferred that this might be the case with Jupiter;* and if so, that the law might be general. (P. 24.)

In spite of his attempt at reasoning, he tells the exact truth on page 23, when he says:

We have already stated that we assumed the perihelion and aphelion points of Jupiter's orbit to be intermediate between his equinoctial points.

Let us examine these remarkable statements.

"Telluric analogy" teaches him that the solstitial points of a planet coincide with the perihelion and aphelion points, or, in astronomical language, the line of the equinoxes is at right angles to the lines of apsides. Now, this is certainly intelligible, and, if true, very convenient, but unluckily it is not true either of the planets in general at the present time, nor is it true permanently of any planet, not even of the earth. Had Mr. Tice consulted "telluric analogy" a little more faithfully, he would have found that owing to the advance of the line of apsides and the retreat of the line of equinoxes, the coincidences between the perihelion and the winter solstice which now exists within eleven days will, in the space of about 5,760 years, become an *exact coincidence between perihelion and the vernal equinox*, and that some 7,000 years ago *perihelion coincided with the autumnal equinox*. Analogy should have taught our author that

there is and can be no fixed relations between these points in any case.\*

Thus far is Mr. Tice furnished with two simple and expeditious, but totally different, methods of "determining" the equinoxes of a planet—

First. They are the points in its orbit farthest removed from the plane of the sun's equator; and

Second. They are the points midway between the perihelion and aphelion points.

But he is not content. A third method, as unlike either of the other two as each is from the truth, is suggested by "telluric analogy."

By following the suggestion that they (Jupiter's solstices) would be found where the plane of his orbit is highest above, or deepest below the plane of the ecliptic, it was inferred that the Jovian tropics and consequent solstices, might be approximately ascertained. Inquiry was instituted in that direction, and it was ascertained that the Tropics or solstices of Jupiter were at the points inferred, and that they exactly coincided with his perihelion and aphelion; and hence of course his equinoxes must be ninety degrees from either of these points. (P. 24.)

I am almost willing to believe that Mr. Tice never wrote these words, and that they were interpolated by a depraved printer, so profound an ignorance of geometry and astronomy do they betray. I should acquit Mr. Tice of all responsibility in the matter did I not find later another sentence in the same vein.

Thus (p. 26) :

In Jupiter the perihelion and aphelion points on his orbit, and his solstitial points exactly coincide, *judging by the plane of the Ecliptic.*

If this third method means anything, it means that a planet's equinoxes occur at its nodes—i. e., those points on its path where it passes through the ecliptic. His analogy seems to be a little weak, as the earth obstinately refuses to go either "above" or "below" the plane of the ecliptic, and that is the reason, perhaps, that we do not hear of this method again. Of course, these three methods of "determining" the equinoxes of the planets would give very different sets of dates, and there is not the slightest probability that any one of them would chance to be true. The statement quoted above, for instance,

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\* In cosmographical questions a thousand years are as a day. Mr. Tice says (p. 120) : "We offer planetary equinoxes for a fundamental principle of meteorology, which are permanently fixed astronomical events that have occurred at their allotted periods as long as the solar system has existed, and will occur as long as it endures." Again, he speaks of calculating when Jupiter "was at either equinox in all time that is past" and "when he will be at all time that is to come." Throughout, Mr. Tice ignores the astronomical fact that no planet has fixed equinoctial points, or, in other words, that in no case is the sidereal year the same as the equinoctial year, and that neither of these agrees with the anomalistic year.



that the perihelion and aphelion points of Jupiter's orbit "exactly coincide" with the points of the greatest distance north or south of the ecliptic is false, at the present date, to the amount of nearly two months, and this interval is a quantity varying all the way from nothing to about three years.<sup>a</sup>

As to which of his three methods Mr. Tice does actually use in forming the tables of planetary equinoxes on which his predictions are based, I am not wholly certain. It is clear that in the case of Jupiter he takes the second. In the case of Saturn he discards all three methods and gives very closely the true dates of his equinoxes, thus showing that, in spite of his assertions to the contrary, he found them set down in the books. The date of Saturn's nearest equinox would be, according to Mr. Tice's first method, June 12, 1878; second method, November 11, 1878; third method, December 2, 1872. Mr. Tice gives November 12, 1877. The true date is September 28, 1877.

As to Venus, Mars, and Mercury a brief examination of the table in his appendix convinced me that he had followed neither method carefully.

I admit that it seems incredible that anyone should have mixed up three arbitrary methods of determining the equinoxes of a planet, as according to my showing Mr. Tice has done. Should anyone doubt the fairness of my report, I beg of him to read our author for himself, but I warn him to take with him a stock of infinite patience, and not to expect to understand the book till he has read it almost literally forward and backward. In extenuation of Mr. Tice's logic I ought to say that I do not think he was conscious of any inconsistency. He was wholly under the spell of his "telluric analogy." The approximate coincidence at the present epoch of the earth's perihelion (January 1), its winter solstice (December 21), and its passing through the sun's equator (December 6) led him to infer that they were equally coincident in the case of the other planets. It would have been very easy for him to see that this was not true in the case of Saturn and only temporarily true of the earth, but he seems to have thought the coincidence incontestably proved by his record of storms. It is fortunate for Mr. Tice that he does not claim absolute accuracy for his equinoctial dates.

All that I claim is that, they are approximations *arrived at from general principles, the only data at my command*. My purpose is to prove that planetary equinoxes affect, and I might say, determine the meteorological phenomena of our Globe. *I could not succeed in my purpose unless I knew, at least approximately, the points on the orbits of the several planets where the equinoxes occur.* (P. 26.)

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<sup>a</sup> Jupiter was at his greatest distance north of the ecliptic August 29, 1874. He was in aphelion October 24, 1874. Mr. Tice must have "instituted" his inquiry in the direction of a very poor almanac.

If his success is only proportioned to the soundness of his deductions from general principles, there is hardly ground for offering him our congratulations.

Here I must leave Mr. Tice's theory of planetary equinoxes, nor do I propose to discuss his meteorological records, nor say much of his tables of dates. It is certain that the latter have no astronomical value and that by his method of verifying dates one set is as capable of "incontestable proof" as another. As to Mr. Tice's planet Vulcan, on which he relies so largely, I have few words to say. I intimated a moment ago that it was chiefly a creature of Mr. Tice's own brain. Let us see if it is not so.

According to his account, having ascertained that the Saturnian and Jovian equinoxes produce sun spots, earth currents, earthquakes, etc., that the equinoxes of the earth, besides intensifying the effect of the larger planets, were especially fruitful in tropical cyclones, it seems probable to him that all atmospheric phenomena were produced by planetary equinoxes. "Acting on this suggestion" he watched the effect of the equinoxial points of Venus, determined as I have already shown. "The result was astounding, fully verifying the suggestion." "Similar satisfactory and astounding results" attended an observation of the equinoxes of Mercury. But the catalogue of phenomena was not yet exhausted.

It was soon discovered that not only many phenomena occurred to which it was impossible to assign a place in any of the known cycles, but which under certain conditions, were *so terrifically energetic that they must have a sufficient though unknown cause.*

I dare not venture an opinion as to the meaning of this last clause. He classed all such unaccounted-for phenomena as "unknown." The unknown class consisted chiefly of cyclones, but there were many auroras, some earthquakes, and sun spots. He noted that these phenomena occurred about every twenty-three days. "The suggestion that they might be referable to Vulcan, the gigantic planet nearest the Sun, soon became a firm conviction." Elsewhere (p. 170) he says:

Other extraordinary phenomena were so far removed from any other known cause, that unless they are due to Vulcan's equinoxes *no other cause can be assigned for them.*

It is obvious, then, that the existence of Vulcan is absolutely necessary to the theory of planetary equinoxes, and the "demonstration" and "verification" of the truth of his "conjecture," that his period of revolution about the sun is forty-six days, is so strong that I almost believe he would have manufactured a new planet out of hand had the suggestion of Vulcan not been already made. To be sure, Mr. Tice says, in an ungarded moment and quite out of keeping

with the rest of the book, that his theory may be vulnerable just at this point of Vulcan. This is in the face of the statement that there is no reasonable doubt of the existence of Vulcan, and in spite, too, of his demonstration of the length of his period.

Now, as to the existence of a planet interior to Mercury, astronomers have not been agreed. At one time some had no doubt that one had been seen; at present, however, most astronomers deny that we have any valid ground for believing in the existence of such a planet.

M. Lescarbault, a French physician, and Mr. Lummis, a business man of Manchester, England, and Mr. Tice claim to have seen an interior planet the 1st of March, 1859, and Mr. Lummis, in March, 1862. Neither of these men was an educated astronomer, and neither had an instrument of much power or accuracy. From the rough data furnished by M. Lescarbault, Le Verrier computed the elements of its orbit, making its period nineteen days seventeen hours. From the data furnished by Mr. Lummis two French astronomers computed the elements, one making its period nineteen days twenty-two hours and the other seventeen days thirteen hours. The world knew nothing about Mr. Tice's observation till the publication of his *Elements of Meteorology* a few months ago.

As to the observation of M. Lescarbault, it ought to be said that at the same hour M. Lais, a French astronomer in Brazil, was examining the surface of the sun, and he—

is positively certain that nothing of the kind was visible, though the telescope that he employed was considerably more powerful than that of the French physician. (Chambers's *Astronomy*, p. 50.)

Mr. Tice knew nothing of the observation of Mr. Lummis and the close agreement of the computed periods. He says that as far as his information goes "Vulcan has been seen but twice—once by its discoverer, M. Lescarbault, March 26, 1859," and by himself September 25 or 26 the same year. No one can fail to be struck with the account Mr. Tice gives of his own observation. He says he had the good fortune of seeing Vulcan make a transit a few days after the autumnal equinox in 1859. A few weeks later it occurred to him that it was not Mercury, as at first supposed.

I then made a record as near as I could of the date, and *its apparent size I recorded as two and one-fourth inches in diameter. As this would give it an enormous size*, I have since got those who also saw it to give me their impression as to its size. I find they vary from *mine a quarter of an inch*, some placing it that much more and others that much less. Probably all these apparent sizes are too great, but they nevertheless clearly establish one thing that the planet is of gigantic dimensions.

You need not be told that such a record as this is totally unscientific and perfectly unintelligible. Apparent size is measured by the visual angle an object subtends and is given in degrees, minutes, and

seconds. It is as dependent on the distance as upon actual size. As far as this record goes, the object seen may have been no larger than a football, or it may have equaled the sun. Mr. Tice elsewhere tells us that Vulcan is fully equal to if not much greater than Venus. If now he will be good enough to tell us how he finds that an apparent diameter of  $2\frac{1}{4}$  inches indicates the size of Venus, we will with equal exactness compute Vulcan's distance from us and from the sun, and, by Kepler's third law, its period of revolution. Mr. Tice is singularly unfortunate in the period which he adopts for Vulcan. You will remember that its discovery dates from March 26, 1859, when the Frenchman saw a dark object passing between the earth and the sun, and that Mr. Tice saw it on September 26 the same year. Now, the interval between these two observations was one hundred and eighty-four days. Mr. Tice's Vulcanian period of forty-six days is contained in this exactly four times, so that between the observations Vulcan made four complete revolutions. One can hardly fail to suppose that Mr. Tice was the more willing to adopt forty-six days as his cycle, seeing that it "comes out even." But it is easily seen that either this period is fatal to his observation or his observation is fatal to this period, for during these one hundred and eighty-four days, or six months, the earth had traveled almost exactly one-half of its orbit and Vulcan had made four complete revolutions, his period or year being forty-six days, so that on September 26 Mr. Tice must have been on one side of the sun and Vulcan exactly opposite, as far as possible from a transit. This is a point which Mr. Tice must have innocently overlooked and which it is impossible to explain away or ignore. What Mr. Tice really saw remains to be told.

Mars could be sacrificed with little inconvenience to Mr. Tice's theory; even Mercury could be spared without serious injury; but Vulcan must be preserved at all cost. Vulcan is the very prop that doth sustain the house. His size, his period, and the dates of his equinoxes are all essential to the theory, and yet I have shown you that you must abandon the size of Vulcan (for that depends solely upon Mr. Tice's observation) or you must give up the period of forty-six days. You can take your choice.

There is another fatal objection to Mr. Tice's Vulcan. A period of forty-six days would involve a mean distance from the sun of about 24,000,000 miles; and as Mercury's mean radius is only about 36,000,000, their distance apart when in conjunction would be only about 12,000,000 miles. Now, the least distance between Venus and Mercury is over 30,000,000 miles, so that the strength of Vulcan's attraction for Mercury would be fully six times as great as that of Venus. Le Verrier accounted for the perturbations of Mercury by supposing the mass of Venus to be increased one-tenth. The perturbing force of Mr. Tice's Vulcan would be at least sixty times too great.

Since the suggestion of Vulcan was first made not an eclipse of the sun has been allowed to pass without the appointment of an astronomer in every party of observers whose sole duty has been to search for inter-Mercurial planets while the intense light of the sun should for a moment be darkened. In addition to this the face of the sun has been under almost constant inspection by trained observers at different stations round the earth, each ready to note the transit of a planet, and yet nothing more has been seen of Vulcan during all these sixteen years. The probability that a planet as large as Venus, and as near Mercury as Mr. Tice imagines Vulcan to be, should thus baffle our observers is very small indeed.

Some confusion exists as to the energy of Vulcan's influence at his equinoxes, though I infer that it is immense when immense energy is exhibited and not noticeable when none is noticed; in fact, it depends upon the weather. This cautious inference is based on such remarks as these:

"Vulcan, gigantic in size and fearfully strong in position, with physical laws operating such as our theory postulates, must at his equinoxes produce just such phenomena as the world has witnessed within the last three weeks" (p. 137)—that is, in July last. Vulcan, you will remember, has an equinox every twenty-three days, so that if he "must produce" each time twenty-one days of heavy rain, we shall have forty-two days of rain, or a new deluge, every Vulcanian year.

Again, we find that Vulcan "carved out nine-tenths of the most violent and terrific phenomena of the Jovial, Telluric, and Venusian classes."

On page 137 he says:

Vulcan's size and position near the sun give him terrific energy, which *he never fails to display at his allotted times.*

And so on with many repetitions.

On the other hand, he says:

*A Vulcanian equinox ordinarily passes without causing phenomena so remarkable as to attract attention.* (P. 29.)

I will close my remarks upon this branch of the subject by calling your attention to a most remarkable period during which not only Vulcan but nearly all the other planets are shorn of their strength and prowess. On page 50 he says: "There was a period of comparative repose from 1819 to 1829," and this was in spite of a "major equinox" of Jupiter, about 10 equinoxes of Mars, 20 of the earth, 32 of Venus, 40 or 50 of Mercury, and 160 of Vulcan.

I am well aware that even if it has been clearly shown that Mr. Tice's explanations of the influence of a planetary equinox are either weak or altogether false, it will be claimed that such influence may



still exist. It is hard to prove a negative, and as no one can deny that even the remotest planet has some influence upon all things terrestrial, an equinoctial disturbance might possibly affect us, just as the falling of an aerolite in China increases the mass of the whole earth, and hence increases the strength of its attraction upon every object on its surface, and this increases the liability of every structure to fall to the ground. This increase is, of course, infinitesimal, but it exists. So with the influence of any planet at any point in its orbit. It is infinitely less than that of the moon even, which was formerly considered the great weather breeder, but which has lately been discarded as wholly insufficient.

I have shown that Mr. Tice's methods of determining the dates of the several equinoxes are confused, contradictory, and incorrect, and yet I can not *prove* that those of Mercury and Venus may not be correct, though the chances are at least a thousand to one against them. Those of Mars, if they were deduced from his perihelion (as I suppose they were), are in error about thirty-four days. Again, although it is not at all probable that any such planet as Mr. Tice's Vulcan exists, he may exist. If he exists, it is highly probable that his orbit lies closely to the plane of the sun's equator, so that Mr. Tice's magnetic theory fails. If he does exist, all the evidences we have fixes his orbital period or year at about nineteen and one-half days instead of forty-six. Now, finally, if Vulcan exists, and his orbit is inclined to the solar equator and his period is forty-six days and he is about the size of Venus, the chances are still twenty-three to one that Mr. Tice has not correctly assumed the dates of his equinoxes, so that the chances on the whole against his all powerful and strictly essential Vulcanian equinoxes are *millions to one*. Still, I suppose, we must allow Mr. Tice's enthusiastic followers (and the columns of our newspapers and journals show that he has a fair following) to take that one chance and cling to it so long as they can see truth in his predictions.

I am quite unwilling to make any examination of his meteorological records. Our knowledge of the weather yesterday, last week, or last year is merely local and very imperfect indeed. I have no idea that a day ever passes without great changes in temperature and in atmospheric pressure, without rain or snow, without driving storm or whirlwind, somewhere on the face of the earth. Mr. Tice predicts, for instance, that there will be a heavy storm to-morrow. Do you doubt you will find one if you will only look far enough? Of course, you can prove any prediction of storm if you will only consult a weather bureau in every land and on every sea. And in examining the past, with a terrible equinox every twenty-three days of from seven to eleven days' duration, and five other equinoxes, *each covering half the calendar* (for the duration of each equinox is one-fourth the

planet's period of revolution about the sun), it is certainly easy to account for everything. The only difficult thing to explain is the occasional interval of repose which, in spite of all the planets, we do enjoy. The electrical excitement of the whole earth resulting from the influence of any of the heavenly bodies must be general in its manifestation and not local, so that local storms, from purely astronomical causes, would seem to be impossible. Mr. Tice has spread out each equinox from the necessity he was under of embracing all the phenomena, until pretty nearly every day in every year is covered up, often several times; and were his predictions consistent nearly every day would be consigned to storms.

For example, according to his table the entire year 1875 is under the shadow of a Saturnian equinox; hence one of Farmer Thomas's distributed predictions is always in order: "High wind—and rain—may be expected—about this time." The six months—February, March, April and August, September and October—are embraced by the equinoxes of the earth. From the middle of February to the middle of last July the equinox of Mars raged. Venus adds her influence this year during February and March, June and July, and from the middle of September to the middle of November. Mercury and Vulcan each cover about half of each month throughout the year. The month of October is especially doomed. The combined influence of Saturn, Venus, the earth, Mercury, and Vulcan is expected to produce terrific results. I have no doubt the prediction will be fully realized. If the valley of the Mississippi chanced to escape terrible earthquakes, tornadoes, and floods, it will certainly be found that there was a low barometer in Brazil, or a whirlwind in New Zealand, or an earthquake in Iceland.<sup>a</sup>

Still, on the other hand, there are occasional openings even in Mr. Tice's table where a little quiet freedom from phenomena may be enjoyed. Let us examine January, 1874. That was, according to Mr. Tice, a white month. Jupiter and Saturn, those mighty disturbers of the peace, were quiet. Venus was, after the 6th, reserving her charms for the spring months. The term of service of the war-like Mars did not begin last year till about the 1st of March. Mercury was off duty till the 28th of the month. That terrible blacksmith, Vulcan, with his sledge-hammer blows, was resting idle from the 10th to the 22d of the month, and the weary earth was still dreamlessly sleeping in the arms of her winter solstice. For once all disturbing forces were stilled and throughout the whole solar system peace and tranquillity reigned supreme for the space of twelve days.

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<sup>a</sup> Since the first reading of this paper October has passed. For a Ticean account of the way in which the prediction was verified the reader is referred to the St. Louis Times, October 29.

Nothing ever happens without a cause, and nothing could happen then, *for there was no cause*. Picture to yourself that blissful period. No rain, no snow; no tearing gale, no ominous calm; no low, no high barometer; no low no high thermometer, for all these are phenomena which prove the influence of a planetary equinox.

Dare the faithful believers in Mr. Tice's equinoxes consult the record of those twelve days, knowing that any physical disturbance would be absolutely fatal to the theory? The sequence of cause and effect is invariable and necessary, and if meteorological phenomena occurred then they were, according to Mr. Tice, without astronomical cause, and hence may occur again without astronomical cause, and the whole equinoctial fabric falls to the ground. I am not going to tell you all that did happen on those few days, for I do not know; but I do not suppose, nor does any one of you suppose, that the face of the earth was absolutely devoid of phenomena during that period. Remember there must be (if you wish to save the theory) no positive changes of any kind other than those invariably connected with day and night. It is not at all a question of degree; it is a question of something or nothing.

Now, Mr. Tice quotes from the Weather Review of January, 1874, low barometer No. I on the 3d, 4th, and 5th, and low barometer No. II on the 6th and 7th, as proving the influence of the Vulcanian equinox of the 4th. Again, he quotes the low barometer No. VII of that month, which took place on the 27th and 28th, as indicating the influence of another Vulcanian equinox on the 27th, and seems well satisfied with the verification. But what of the four low barometers, Nos. III, IV, V, and VI, occurring during the middle of the month, each one of which was a storm center traveling across our land?

All these storms actually took place during this quiescent interval in spite of the obvious impropriety of their doing so and in spite of the deadly injury they inflicted upon this wonderful theory.

I have examined the Weather Review for that month, and I find that storm No. IV originated in the Mississippi Valley and was first marked as central in Missouri on the morning of the 13th. It moved to the eastward with a mean velocity of 50 miles per hour, causing very high winds on the eastern coast.

During the 15th and 16th of the month a severe storm prevailed on the Pacific coast, extending from central California to the west coast of British America, and the barometer fell to the unusual reading of 29.06 inches at Portland, Oreg. At Fort Garry the barometer stood at 29 inches, the lowest reading during the month.

In examining the Weather Report of this month Mr. Tice found the storms which showed the effect of Vulcan's equinoxes because he was looking for them, but failed to note the greatest phenomenon of



the month because his theory did not require him to examine these uncaused storms.

What took place meanwhile in Europe, Asia, Africa, South America, Australia, and on the oceans stretching to either pole we do not know, nor is information needed, for a single uncaused storm is as much a stumbling block in Mr. Tice's way as though without astronomical cause an earthquake should lay a city in ruins.

It must be remembered that I have not the slightest faith in the accuracy of a single date in Mr. Tice's tables, excepting those of the earth and possibly those of Saturn, and that this test of their value has been made for the purpose of showing how utterly worthless they are to meteorology. Mr. Tice will of course explain the phenomena of January last year by calling to his aid Uranus or Neptune,<sup>a</sup> those planets so inconceivably remote that in comparison Jupiter is a near neighbor, or some other planet still unknown.

Mr. Tice's book contains neither table of contents nor an index, nor does there seem to be any method in its arrangement, but everything is tumbled into its pages in the utmost confusion. There is a new statement of his theory on about every twentieth page, and things are given differently in different places. Throughout the book we find Mr. Tice fighting helplessly and hopelessly against his convictions, so anxious is he not to accept anything as true that is not incontestably proved. On the last page he says: "We have literally and rigidly obeyed the injunction of Locke, 'In science write demonstratively.'" Again: "I love and venerate facts." In commending his theory to the teachers of natural science in our elementary schools he says: "What now passes for Meteorology is less like science than vegetable oysters are like real oysters. *Better teach nothing than teach error.*" (The italics are his.) And yet so overwhelming are the proofs he meets with on all hands that he surrenders without discretion, and we find him repeatedly confessing himself "satisfied" and "convinced" that propositions have been "demonstrated," "verified," and are "irrefragable," whose probability even another would not admit for an instant.

Here I must say adieu to Mr. Tice and his ingenious theory. He leaves the question of meteorology just where he found it—involved

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<sup>a</sup> The awful earthquake of 742 was partly owing to a Saturnian disturbance brought about as usually by an equinox of either Mars, the Earth, or Venus. Mercury may have contributed its influence; Jupiter is ruled out; Vulcan—the "Terrible"—with his sixteen fearful equinoxes, is ignored, but Mr. Tice adds, with charming simplicity and candor, "*besides either Uranus or Neptune may have been at their equinoctial points and thus aided in producing the convulsion.*" (P. 43.) What sublime extravagance is this! It is as though he should pick a few grains of sand on the seashore and say: "These it was which alone turned back the tidal wave!"

in great difficulty and obscurity, but still yielding day by day and inch by inch to the resolute army of students and observers who are besieging it on all sides.

In concluding this hasty and imperfect examination I am almost led to apologize for the large demand made upon your time and attention. So baseless have we found our author's theory and so deficient are his arguments that the book seems hardly worthy your serious consideration. My purpose has not been to publish a theory of my own, for I have none, but to help clear the way for the coming of the true science of meteorology which the future certainly has in store for us.



# DISCUSSION OF LONG-RANGE WEATHER FORECASTS.

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By Professor E. B. GARRIOTT.

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## INTRODUCTION.

Historical references indicate that at an early period in the history of the world man began to associate certain kinds of weather with certain appearances of the heavenly bodies, and that with advances in human knowledge meteorology and astronomy became associated branches of science that embraced all appearances of the sky and the visible phenomena of the atmosphere. In Babylonia rotations of the weather were defined by meteorological and astronomical observations, and in Egypt, where material prosperity has ever rested on the annual rise and fall of the Nile, the periodic appearance of certain constellations revealed the recurring seasons of drought and flood. The Romans and the Greeks were close observers of the weather, and it is a matter of record that during several centuries before Christ they collected and systematized records and traditions regarding the various phenomena of the atmosphere.

Meteorology was not wholly disassociated from astronomy until Copernicus solved the problem of the solar system. The fact was then made clear that the general character of the seasons was controlled by practically immutable astronomical causes, and that the weather forecasts of the ancients were merely statements of climatic or general weather conditions that by observation had been associated with the heavenly constellations. . In other words, the system of weather forecasting that had for a basis a calculation of supposed stellar influences was effectually discredited when the sun and the movements of the earth around the sun, and not the stars, were found to be responsible for the weather that is peculiar to the several seasons. An explanation of the apparent success of the system is found in the sharply marked character of seasonal weather in southern Asia and the countries bordering on the Mediterranean Sea, and an additional cause for abandoning the system is found in the fact that as centers of civilization shifted to more northern latitudes the weather of the various seasons exhibited greater irregularities and variations.

In the seventeenth century, the invention of the thermometer, credited to Galileo, and later the invention of the barometer, by Torricelli,

afforded means for accurately determining the temperature and weight, or pressure, of the earth's atmosphere, and observations obtained by the use of these instruments facilitated a definition of climatic features and permitted more accurate interpretations of the meaning of local weather signs. During the seventeenth and eighteenth centuries long-range weather forecasting, with other practices of an astrological nature, gradually disappeared from the field of legitimate science. During this period, however, men of recognized scientific attainments were actively engaged in investigations regarding the composition, physical properties, and phenomena of the earth's atmosphere, and climatical problems were systematically considered. Instrumental observations, and especially those furnished by the barometer, aided materially in determining the character of impending weather changes, and barometric indications of the approach and passage of storms were of great value to navigators.

Previous to the nineteenth century man possessed no knowledge of the laws that govern the weather, nor of the mechanical processes that are employed in the production and propagation of storms and other well-marked phenomena of the atmosphere. He had noted, without knowing the reason therefor, that in the Northern Hemisphere northerly winds are usually attended by low temperature and southerly winds by rising temperature; that in the middle latitudes easterly winds are generally followed by rain or snow and westerly winds by clearing or fair weather; that certain cloud formations and movements indicate certain kinds of weather, and that manifestations of atmospheric moisture are of value in determining the character of impending weather changes. He had learned by observation to interpret the meaning of effects produced by certain atmospheric conditions on objects animate and inanimate, and had acquired an intimate knowledge of astronomical events that govern the seasons. About the middle of the eighteenth century Benjamin Franklin, who first conceived the idea that electricity and lightning are identical, discovered that the northeast storms of the Atlantic coast of the United States actually advance from the south or southwest and are first experienced on the southern coasts.

A formal announcement of the law of storms was made by William C. Redfield, of New York, in 1821. Redfield's deductions were based upon observations taken along the Atlantic coast of the United States. He found that the whole of the revolving mass of air that composes the storms of that region advances with a progressive motion from southwest to northeast. In later years he drew conclusions regarding storms in general that have not been materially modified by subsequent research.

The history of meteorological progress during the last half of the nineteenth century is embodied in many reports and publications, ref-

erence to which will be made in connection with the subject under discussion. The sum of the achievements of this period in practical and theoretical work and investigation is represented by a rapidly increasing collection of data and facts that afford a sure foundation upon which future work may rest.

The United States Weather Bureau, which possesses facilities that permit it to surpass all other meteorological services in the accuracy of its predictions, now issues forecasts each day for periods of one and two days in advance, and at times the period is extended to three or four days. This is the greatest length of time for which calculations based upon present available data and information can be made. The data referred to is received daily by telegraph from an area that embraces the United States, Canada, the western Atlantic Ocean, the West Indies, and Mexico, and the forecasts are results of careful studies from day to day of atmospheric changes, movements, and developments that appear within the region of observation. The daily calculations thus prepared are subjected to a rigid verification that yields 80 to 85 per cent of verified forecasts that have been made in detail for each twelve hours of the forecast period. In the case of forecasts of severe storms, well-marked cold waves, frosts, and other phases of the weather that are calculated to cause serious loss or inconvenience to commercial and industrial interests, and also in the forecasting of floods in the principal rivers of the country, the forecasts are almost invariably timely and accurate. While the predictions thus issued are not long-range forecasts, it is interesting to note that the period for which forecasts have been officially and regularly made has been extended during the last thirty-three years from eight hours to forty-eight hours without a lowering of percentage of verification.

A further extension of the forecast period depends in a measure on an enlargement of the area covered by telegraphic reports of simultaneous observations. In weather calculations based on recognized physical laws time limitations must be fixed by the period of transition over the region of observation of well-defined storms. If the region has a longitudinal width of 3,000 miles and the average eastward progress of storms is 700 miles a day, the time that will elapse from the first to the last appearance of an average storm within the region of observation will be between four and five days. Allowing the storm one day to enter the region after the first indications of its approach are observed on the western border, and another day for its setting in ahead of the actual center of disturbance, there remains less than three days for forecasts of its advance to the easternmost parts of the region. Assuming that the storm follows the time and route schedule made on its first appearance, it is reasonable to expect that its passage will be followed by two or three days of fine weather, and

predictions based on this assumption, while not strictly legitimate, are nevertheless statements of conditions that are natural sequences to the conditions forecast and depend for their verification upon a justification of the original forecast. It appears, therefore, that with present facilities the forecast period can at times be extended to five or six days. In view of this statement, and with a due consideration of the necessarily slow advances that are usually made in the arts and sciences, the progress of weather forecasting during the last third of a century has been remarkable, and another quarter of a century will undoubtedly show a corresponding advance. In the meantime data, knowledge, experience, and honest, well-directed effort will be persistently applied to the problem of practical meteorology in the belief that the particular laws of nature that may control rotations of the weather will be determined.

#### THE BASIS OF LONG-RANGE FORECASTS.

“Planetary meteorology” is the term applied to the practice of the more prominent long-range forecasters, and planetary meteorology is one of the relics of astrology; fortune telling is another. When advances in astronomical knowledge made clear to the world at large that the fixed stars do not exercise an influence upon the weather, exponents of the weather branch of the ancient art of astrology with one accord placed upon the moon and several of the planets of the solar system the responsibility of regular and irregular forms of weather. To the moon, however, was given the burden of the responsibility, for be it known that centuries before the Christian era the periods of the new and full moon were associated with current weather, and rotations of certain weather types were supposed to attend a nineteen-year lunar cycle, during which the new and the full moons are repeated on corresponding days of the month.

Some of the most financially successful long-range forecasters of the present time base their forecasts on the moon's path with reference to the ecliptic and the earth's equator, and strengthen their statements by allusions to mysterious Vulcan, eclipses, occultations, and quotations from the Scriptures. Others employ the nineteen-year moon cycle and fall back upon a fund of mysteriously acquired superhuman wisdom and, incidentally, upon past records of the weather; and the manipulation of past records, which have a positive value in climatic work, represents their stock in trade. Other prophets appear from time to time and, lacking in “business” faculty, quickly disappear.

A careful consideration of the merits of the moon as a controller of the weather presents a number of reasons why the claims of fair Cynthia's disciples should be given respectful consideration. The belief is entirely plausible that the earth's nearest neighbor should assume



a part in the management of her affairs. The moon's aspect is changing every day, and so is the weather. The phases of the moon change once a week, and we have a storm about once a week. The storms may be either "regular" or "reactionary;" that is, we may get them coming or going, either before or after the change in the moon. Then there is a certain sentimental feeling for the moon that is due to an inherent regard in the human breast for the mystical and the mysterious. And, finally, the formidable interrogation is launched against unbelievers: The moon influences the tides of the oceans, why should it not influence the weather?

With the burden of proof thus placed upon the scientist, who demands corroborating facts before he can accept in all faith unsupported assumptions of superior wisdom, the long-range weather forecaster continues to exercise, for a consideration drawn from the gentle public, the time-honored practice of playing upon the fancy of the credulous.

#### OPINIONS REGARDING THE INFLUENCE OF THE MOON ON THE WEATHER.

The principal object of this paper is to present a summary of the quoted opinions of prominent meteorologists who have endeavored to justify the practice of long-range weather forecasts by facts or theoretical deductions based on known physical laws. A consensus of the opinion of meteorologists appears to be that while the moon undoubtedly exerts a certain influence on the earth's atmosphere the influences are not directly and noticeably contributory to marked normal or abnormal weather conditions.

In a letter delivered by Prof. Dr. J. M. Pernter to the Association for the advancement of Scientific Knowledge, Vienna, January 14, 1903, the following remarks were made regarding the moon as a weather forecasting medium:

The moon is credited with being the principal dominator of the changes of the weather. The weather is supposed to change by preference with the moon; therefore the new moon and the full moon especially possess the power of influencing the weather, and one of the most widely spread weather rules is that the weather changes with the new moon and with the full moon. However, by many others the first and last quarters are considered of greatest importance. Especially clever observers of the influence of the moon upon the weather pretend to have also observed the distinctive individual influences of the phases known as octants. In general the opinion is very widespread that the decreasing moon exercises a weak and the increasing moon a strong influence. Thus far the theory of the influence of the moon on the weather is the direct result of the popular belief in the moon, without regard to any scientific basis.

Rev. F. L. Odenbach, director of the meteorological observatory, St. Ignatius College, Cleveland, Ohio, has written as follows (Monthly Weather Review, June, 1903):

With reference to the rain theory of Mr. H. C. Russell, of Sydney, New South Wales, I have looked up the extensive literature on the subject extending through



the two last centuries up to date. An immense amount has been written on the subject.

The sum and substance of all the work done along this line has failed to bring out anything that might be considered a law or be used as a safe rule in questions of climatology or weather forecasting.

I myself think that the moon (and why not the sun and the planets?) *must* have some influence on our weather. Yet this influence must be so slight or so concealed that all these years of observation and hard work have not resulted in anything worth considering.

The great objection I have to this new exposition of Mr. Russell is that from the start he distinguishes between the rainfall on the coast and that of the interior. Why? In this point Mr. Russell follows all of his predecessors. The rule is bolstered up with exceptions and conditions, subconditions, and special combinations until the application becomes a mere guesswork. My general impression on the subject is that about as much time has been wasted on this matter as on the "Perpetuum mobile" and with about the same success. Being in this mood I think it best not to write anything for the Review for fear lest some might take up the matter and neglect other lines of much more importance and far greater utility.

The rain theory of Mr. H. C. Russell, referred to, is discussed as follows by Prof. Cleveland Abbe in the Monthly Weather Review for November, 1902:

Mr. H. C. Russell, director of the observatory at Sydney, New South Wales, has published in the Journal and Proceedings of the Royal Society of New South Wales, for the year 1901, a memoir on the relation of the moon's motion in declination and the quantity of rain in that colony, in which the author concludes "that rain is clearly shown to come in abundance when the moon is in certain degrees of her motion south; but when the moon begins to go north then droughty conditions prevail for seven or even eight years. This phenomenon repeated for three periods of nineteen years each constitutes a marvelous coincidence such that there must be a law connecting the two phenomena.

The influence of the moon on the weather is a matter that will not be downed by the exercise of any amount of common sense. According to the most ancient notions, the moon ought to have and must have a controlling influence in excess of the sun's, and everyone who seeks to demonstrate its power is liable to become infatuated with the study. The moon has so many variations north and south of the equator, north and south of the ecliptic, to and from the earth, from new moon to full moon, conspiring with the sun and opposing the sun, that it does seem as though one ought to be able to make its periodical oscillations agree with some of the many variations in the aspect of the weather. However, we know of but one relation between the moon and the earth's atmosphere that can be said to have been settled upon a rational basis, and that is the matter of atmospheric tides. Laplace stated that the semidiurnal lunar tide in the atmosphere ought to amount to about 0.003 inch of barometric pressure for equatorial stations, and this agrees with the results of observations carried on at Batavia, Java. His formulæ also showed,\* although we believe he did not state the fact, that as the moon moves north and south of the equator monthly, there ought to be a fortnightly tide, or a general pull of the atmosphere southward for two weeks and northward for two weeks. This we believe was first demonstrated as an observable quantity by A. Poincaré, a civil engineer of Paris, and a member of the Meteorological Society of France. From his articles published by that society in 1885-1888 we learn that the average barometric pressure on parallels of latitude around the whole globe,

as measured by the international maps published by the United States Weather Bureau, gives the following results: The pressure on latitude  $40^{\circ}$  minus that on latitude  $10^{\circ}$  is  $+1.88$  millimeters when the moon is in the extreme south and  $+4.82$  millimeters when the moon is in the extreme north. The normal difference is  $+3.35$ . This indicates that when the moon is farther north there is a slight accumulation of atmosphere in the Northern Hemisphere amounting to  $1.47$  millimeters, or  $0.06$  inch of pressure on the parallel of  $40^{\circ}$ .

Now, all lunar phenomena go through rather rapid periodic changes. What happens in one part of the lunar month is offset by an opposite effect in the other half of the month, or what happens when the sun and moon conspire is offset by an opposite effect a few months or years later, when the sun and moon oppose each other. When the moon is far south and begins to go north, according to Mr. Russell, droughty conditions prevail and continue for seven or eight years. But the strange part is that the moon begins to go north from her extreme southern position every month without exception, not only just before the seven or eight year drought, but during the whole of that long period, and continues to do so during the whole of the succeeding rainy period. How can her beginning to go north be rationally supposed to be a basis for predicting droughts in one case and rains in another?

But if we lay aside these vagaries about the moon and recognize Mr. Russell's meteorological induction that droughty conditions do prevail for seven or eight years in Australia, followed by years of rain, and that this cycle of droughts and rains has been repeated about three times since 1840, then we have a fair observational basis upon which to build a rational explanation. Now, this periodicity, or rather the irregular succession of good seasons and bad seasons, is a fact recognized in every portion of the world. We also have enough data to show that in most cases a drought in one portion of the globe is accompanied by rains in other portions, and that the regions of excess and deficiency of rain move over the surface of the globe month by month and year by year. They do not move in courses so nearly parallel as to justify long-range predictions any more than do our storm centers, but the movements are certainly governed by laws, and we can begin to generalize as a first step in the process from induction to deduction.

For instance, floods in the upper Nile, due to rains in the highlands of central Africa, mean that an unusual proportion of moisture has been taken from the southeast trade-wind current, and that, therefore, when that has been turned northeastward over the Indian Ocean and has become the southwest monsoon of India, it will bring droughts over the western portion of that country. A drought in New South Wales or on the southeast side of Australia means a deficiency in the eastern winds blowing on that coast, and especially so in the rainy season, or December, January, February, and March. But this means that the great area of high pressure over the Indian Ocean at latitude  $30^{\circ}$  south has been pushed farther west than usual, or, in other words, that the general circulation of the atmosphere in that region has been disturbed. Now, such a disturbance, continuing over several months or even years, can hardly be produced by the rapidly changing moon; it might be due to secular changes in the quantity and quality of the solar heat, but is most of all likely to be simply the result of accumulations of pressure, temperature, and moisture in various portions of the earth's atmosphere. Australia has about the same area as the United States, but lies on the average about  $15^{\circ}$  nearer the equator. This latter feature gives it soil temperatures and monsoon influences similar to those that prevail in northern Africa, so that it may itself produce an appreciable disturbance of the general circulation in the southern half of our atmosphere. But the principal cause of the droughts in Australia and India is undoubtedly to be

found in the changes going on periodically in the relation between the general atmospheric pressure and resultant circulation in the south and in the north, or between Cape Colony and Australia, China, and eastern Siberia. In this large portion of the globe a system of circulation prevails that is affected but comparatively little by what goes on to the west of it and to the north of it. A large quantity of air enters into this region from the Antarctic Ocean and passes out of it as the southwest monsoon of southern Asia to eventually become the westerly winds of the North Pacific. We may, therefore, look for some connection by this roundabout way between the droughts and rains of Australia or southeastern Asia and those of northwestern America.

It may be interesting at this point to quote two brief utterances regarding the effect on the weather of lunar influences that reflect the attitude of the scientific world toward this matter in 1868 and thirty-five years later. The first was made by Alexander Buchan, M. A., secretary of the Scottish Meteorological Society, and was, in part, as follows:

It is an opinion that has been long and popularly entertained that the changes of the moon have so great an influence on the weather that they may be employed with considerable confidence in prediction. That the moon's changes exercise an influence so strongly marked as to make itself almost immediately felt in bringing about fair or rainy or settled or stormy weather, an examination of meteorological records, extending over many years, conclusively disproves.

The following remarks by Prof. Alfred Angot, of the Central Meteorological Bureau, in Paris, that appear in the Monthly Weather Review for July, 1901, will conclude the presentation of direct testimony concerning lunar influences on meteorology. In a final summary of the general subject of long-range forecasts, however, further comment will appear regarding the alleged domination by the moon of terrestrial weather:

The idea that the moon exerts any influence on meteorological phenomena goes back to the most ancient times; there is no belief that has left more traces in the popular traditions in regard to the weather, nor that has been the subject of more controversy.

Let us recall that the time occupied by a true or sidereal revolution of the moon is 27d. 7h. 43m., or 27.322 days; the apparent or synodic period, after which the sun, earth, and moon return to their same respective positions, is a little longer, viz. 29d. 12h. 44m., or 29.531 days. It is after this latter interval that the *phases* of the moon again become the same. The *anomalous revolution* or mean value of the intervals of time separating two consecutive passages of the moon through its shortest distance from the earth is 27d. 13h. 19m., or 27.555 days. Finally, the orbit of the moon has a mean inclination to the ecliptic of  $5^{\circ} 8' 48''$ ; the maximum declination of the moon therefore varies between  $18^{\circ} 10'$  and  $28^{\circ} 45'$ , while the maximum declination of the sun is  $28^{\circ} 27'$ .

The moon imparts to us only a very small proportion of the light and heat that she receives from the sun. The heat that she sends toward the earth is so feeble that the most powerful instruments and the most delicate methods of measurement must be employed to discover it; there can, therefore, not be any question of a luminous action of the moon and much less of a caloric action,

and we can scarcely think of anything else but an attraction analogous to that produced by the tides on the great masses of water of the oceans. It is therefore necessary to first seek to discover whether the action of the moon does produce atmospheric tides that show themselves by the periodic variations in the height of the barometer.

If we observe the pressure at the lunar hours, that is to say, when the moon passes the meridian and she is distant from it  $15^{\circ}$ ,  $30^{\circ}$ ,  $45^{\circ}$ , etc., and if we take hourly means of the values observed during a very long period of time, in order to eliminate the disturbances, these means will certainly give an indication of a lunar tide, but extremely feeble; it will only be found at the equatorial stations and disappears entirely in the middle latitudes. At Batavia the maximum pressure occurs a half hour or an hour after the upper and lower passages of the moon over the meridian; the minimum occurs from six to seven lunar hours after the maximum; the total extent of the variation is only 0.11 millimeter, which corresponds to a column of water of about 1.5 millimeter (or one seven-thousandth part of the standard average atmospheric pressure.—Ed.).

The insignificance of the diurnal lunar variation of pressure indicates that this must also be true of the variation corresponding to the revolution of the moon around the earth; that is to say, to the phases of the moon. In Batavia the pressure is the feeblest at the time of the new moon and most powerful shortly after the period of full moon. The total extent of this oscillation does not reach 0.2 millimeter. The diurnal rotation and the synodic revolution of the moon therefore cause tides in the atmosphere as well as in the oceans, but the atmospheric tides are so extremely feeble that they scarcely exceed the limit of accuracy of the barometric observations.

The study of the influence of the synodic revolution or of the phases of the moon upon other meteorological phenomena produces results which are absolutely contradictory, and which have been discussed in detail by Arago and more recently by Van Bebber. We shall therefore limit ourselves to summarizing briefly the conclusions arrived at by them.

The temperature, the cloudiness, and storms do not show any periodicity in relation to that of the phases of the moon. In Germany north and northeast winds seem most frequent in the period of the last quarter of the moon and most rare in the first quarter; the southwest winds show an inverse variation. But this law has not been verified in any other countries.

At Paris and in Germany the maximum number of rainy days occurs between the first quarter and the full moon; the minimum number between the last quarter and the new moon. The relation of the maximum to the minimum is 1.26 at Paris and 1.21 in Germany. It would, therefore, at first sight seem that there is here a true law and that the prospects for rain are greater by a fourth or a fifth after the first quarter than after the last; but even this would be too slight a difference to be made use of for a serious forecast. Besides, this law does not hold good for the south of France. At Orange, for example, the minimum of days with rain occurs between the full moon and the last quarter and at Montpellier in the first quarter. If there is any relation between the phases of the moon and the rainfall, this relation is, therefore, very complex and variable from one region to another.

The study of the changes of the weather has produced still less convincing results. In discussing the observations made at Padua in the last century, Toaldo found that, according to the popular belief, the weather is much more variable at the time of new moon than at the other lunar periods. But convinced in advance of the existence of the influence that he wished to demonstrate, Toaldo attributed to the action of the new moon the changes in the weather occurring one or two days either before or after, whereas for the rest

of the lunar period each day was considered separately. If, now, rigorous computations be made, giving to each day the same value, there will no longer be found any trace of the influence of the phases of the moon on the changes of the weather. During the past few years the study of the influence of the moon has been again taken up in a manner apparently more scientific. In the first place, all idea has been abandoned of finding any relations between the meteorological phenomena and the phases of the moon; that is to say, the synodic revolution which represents only the relative positions of the earth, the moon, and the sun. Then the anomalistic revolution was studied, which corresponds better to the respective real positions of the earth and the moon. But, above all, the position of the moon in declination has been compared, not with any special local meteorological phenomenon—such as temperature, rainfall, changes of the weather, etc.—but with the distribution of pressure over the surface of the globe as a whole.

The fundamental idea of these researches is that the movements of the moon in declination may lead to general displacements of the air or a balancing between the tropical regions and the higher latitudes, and thus cause periodical changes, such, for example, as in the boundary of the trade winds and in the law of change of pressure with latitude. We should then understand that a movement of a zone of high pressure, for example, might cause fine weather on one side of the zone and at the same time foul weather on the other side, and that these variations, which at first sight seem contradictory, might nevertheless be due to one and the same cause. These studies are, however, of too recent date and still too undeveloped to have already given results that may be considered as sufficiently conclusive and general. It is, however, interesting to mention them here, since by continuing to work in the same lines we may, perhaps, succeed in discovering the true relations between the moon and the phenomena of the weather, since the earlier researches have not brought about any positive conclusion. On the whole, in the present state of our knowledge, it can not be affirmed that the moon does exert any influence upon the weather, but at the same time it should not be denied that this influence may possibly exist. In any case it would show itself by complex phenomena, such as the displacement of the zones of high and low pressure, and might cause very different results in different regions.

In concluding the examination of the various opinions in regard to the influence of the moon, it may be well to say a word on the opinions concerning the *lune roussée* or harvest moon. This name has been given to the lunar period which, beginning in April, has its full moon either in the second half of that month or in the month of May; if there are two new moons in April it is with the second that the harvest moon begins. Agriculturists declare that often at that time, when the sky is clear and the moon shines brightly during the night, the tender buds are frozen and turn red, even although the temperature of the air does not fall below freezing; nothing of this nature occurs if the moon remains hidden behind the clouds. The explanation of this phenomena is very simple and the moon has no part in it. When the sky is clear and the atmosphere dry and transparent (this is the time when the moon shines most brightly), the temperature of bodies subjected to the nocturnal radiation falls far below the temperature of the air. If during the day the temperature has not been very high the nocturnal radiation may then chill the plants below freezing and they will freeze although the air remains at a higher temperature; on the other hand the plants will not be frozen if there are clouds to diminish the radiation. The conditions that lead to these freezings are, therefore, a clear sky and a relatively low temperature during the day. At the end of May or June the mean temperature is generally too high to allow us to fear these



freezes, although they do occur sometimes. Before the commencement of the harvest moon—that is to say, at the end of March or the beginning of April—the temperature is lower than during the harvest moon itself; the conditions are, therefore, much more favorable for freezing by radiation; but as the vegetation has not yet begun these freezes do not cause any damage and do not attract any attention. We have here to do with a very simple phenomenon in which the moon plays no other part than merely to indicate by its brilliancy when the sky is pure and transparent.

In the countries in the south of France, where the vegetation is more advanced than in the center and the north, the critical period of vegetation is no longer during the harvest moon, but during the lunar period which precedes it.

#### OPINIONS REGARDING THE INFLUENCE OF THE SUN IN THE PRODUCTION OF RECURRING TYPES OF WEATHER.

Seasonal weather is a product of fixed astronomical causes modified by latitude, topography, and position with regard to land and water surfaces, and a belief is prevalent that departures from seasonal weather is due directly or indirectly to variations in the output of solar energy. There is also an inclination toward a belief that certain aspects of the sun may be responsible for certain types of weather, and it is deemed not improbable that solar conditions of causation may have defined periods of recurrence. At present, however, all is speculation regarding the relation of the sun to possible periodicities of the weather, and the employment of possible synchronous changes in solar and terrestrial conditions in the practice of weather forecasting necessarily awaits an accurate determination and association of conditions and changes of this character. Certain it is that claims of discoveries in this direction that may be made by men of standing in the world of science will be accompanied by proof of the discovery and of its applicability to practical work. In the meantime there are threads or traces of facts that justify further investigation, and in the conduct of this investigation the most approved methods and appliances and a most comprehensive appreciation of the latest advances in practical and theoretical astronomy and meteorology must be employed to achieve results.

Interest in the meteorological possibilities of a study of solar conditions has been particularly active during the last five years, and the literature of this period that summarizes practically all that has been accomplished in this work will be reviewed.

India presents a favorable field for comparison between solar conditions and meteorological phenomena, and the result of systematic and well-directed efforts to associate conditions of the sun, and more especially the appearance and disappearance of sun spots, with unusual delays and early terminations of the southwest monsoon rains is presented in the following extract from a paper by E. Doug-

las Archibald that appeared in Symon's Meteorological Magazine for July, 1900:

\* \* \* Various attempts have been made to correlate the occurrence of Indian famines with the variations in the energy derived from the sun corresponding to the periodic changes in the spotted area; but though there are evidences of parallelism, the relation is not a simple or regular one. The condition of the sun is probably a contributory *vera causa*, but not a *maxima causa*.

Reacting conditions, initially determined by changes in the position of antarctic ice, slight deflections in the equatorial ocean currents and in the vertical and horizontal position of upper atmospheric air streams of abnormal condition, such as those recently shown to exist by means of kite observations, are likely to be far more potent prime causes of seasonal abnormalities than the small and fairly regular changes which appear to follow the appearance and disappearance of sun spots. \* \* \*

\* \* \* Apart from these six-monthly barometric waves (referred to as having been observed at times in connection with Indian weather), there is little doubt that certain influences are at work in the atmospheric circulation over the Indian area which cooperate with other periodic factors in tending to cause excess or defect of rains at intervals of nine to twelve years. What these influences are it is difficult to say. To some extent they appear to be associated, as we have above noticed, with the 11-year period of sun spots; and certain irregularities of the two phenomena are, in my opinion, no argument against their covariation, and even casual connection, since the northern and southern Indian areas are at seasons meteorologically distinct. So far as the facts go they may be summarized as follows:

1. Extensive droughts occur in the dry area of southern India, embracing in particular northern Mysore, south Deccan, southwest Hyderabad, but occasionally reaching Guzerat and parts of the Bombay and Madras presidencies, at intervals of nine and twelve years and usually, but not regularly, about a year before the sun-spot minimum. When the conditions are sufficiently acute famine occurs in the ensuing year.

2. A severe drought in the peninsula of southern India is followed by a severe drought and ensuing famine in northern India in about five cases out of seven.

This sequence is attributed by Mr. Eliot to the empirical law of opposition in the seasonal rainfalls of northern India and the general monsoon conditions of northern and southern India.

Thus a drought and high barometric pressure in southern India usually coincides with low pressure and heavy summer monsoon in northern India. This latter tends to be followed by a heavy winter rainfall, and this again by the compensatory law, first discovered by Professor Hill and the writer in 1877, by subsequent deficient summer rainfall in northern India.

3. Besides these, summer droughts tend to occur in northern India alone in years of maximum sun spots, connected in some way with the abnormal high pressure over western Asia which prevails at such epochs.

There is thus a double periodicity of drought and famine in north India and a single periodicity in south India in the sun-spot cycle, though the relation between the phenomena is too spasmodic and irregular to be utilized as a reliable factor for prevision.

Brückner's empirical cycle of thirty-five years, whatever its cause, undoubtedly exists in the Indian area. Under the title of the "grand cycle" it has long been known in Ceylon, and it is quite possible that the present famine, which from its area and the immense number (6,000,000) of people who are still

on relief works appears to be the greatest famine of which we have any record, may be the aggregate effect of the simultaneous occurrence of a Brückner with a sun-spot cycle drought.

The problem is similar to that of the combinations of harmonic undulations which cause unusual tides, and its solution and application to prevision can only be effected by systematic study of the billows and ripples which appear in the long and short records of barometric pressure over wide areas for many years.

In a paper published by permission of the Secretary of the Smithsonian Institution in the *Monthly Weather Review* for April, 1902, C. G. Abbot discusses "The relation of the sun-spot cycle to meteorology" as follows:

Since the discovery of the periodicity of sun spots a large space in scientific literature has been occupied by articles tending to establish some connection between this and variable terrestrial phenomena. It is natural that it should be inferred that any considerable change in the sun must bring about numerous direct or indirect consequences upon the earth, but one who has given the subject no attention will be startled to find that the following list contains but a portion of the terrestrial phenomena asserted, on more or less authority, to be influenced by the sun-spot cycle: Magnetic and electrical conditions (including the aurora borealis), air temperature, barometric pressure, humidity, the winds, cloudiness, rainfall, depth and quantity of discharge of rivers, retreat and advance of glaciers, number of shipwrecks, bank failures and commercial crises, the crops, prices of grain, famines, wars, and even flights of butterflies.

It would probably be easier to show that the number of articles concerning sun spots in scientific periodicals has an 11-year period than to prove all the above-mentioned relations to the general satisfaction. For the purposes of this paper it will be sufficient to assume as proven that terrestrial magnetism and the aurora borealis are affected when spots appear upon the sun, and that while the evidence is less simple in regard to the meteorological elements—temperature, barometric pressure, humidity, cloudiness, and rainfall—yet there is good reason to think that these, too, are somewhat connected with the sun-spot cycle.

#### HOW SUN SPOTS MAY BE ASSOCIATED WITH TERRESTRIAL PHENOMENA.

The question before us is this: Through what physical connection is the presence of sun spots associated with variations in terrestrial magnetism and with meteorology? The question suggests the possibility either of a single or a dual link between the solar and the terrestrial occurrences. It is conceivable, for instance, that the sun spots are associated with great electro-magnetic disturbances upon the sun which are propagated to the earth and directly disturb terrestrial electricity and magnetism, and that such a disturbance of atmospheric electricity as thus occurs may indirectly induce or prevent the accumulation of clouds, which in turn may bring on differences in temperature, barometric pressure, and rainfall. Again, it is conceivable that sun spots are associated with an increase or a diminution of the sun's radiation, which obviously would directly affect meteorology, and indirectly might affect terrestrial magnetism and electricity. Still again, it might be that the sun spots are associated with great electro-magnetic disturbances in the sun and with an increase or diminution of solar radiation, and that in this dual way the terrestrial changes are directly brought about.

The second of these hypotheses is, I think, untenable as an explanation of the magnetic effects. These are too quick and pronounced to allow us to suppose



for a moment that they are the indirect results of increased or decreased solar radiation. We may, then, admit that electro-magnetic disturbances are propagated from the sun at the time of sun spots. It would be difficult, however, to prove or disprove that these are competent to indirectly produce the observed fluctuations of temperature, pressure, and humidity which have been connected with the sun-spot cycle. Almost without exception writers on this subject who have ventured an opinion have attributed these meteorological changes to alterations in the amount of the solar radiation. There seems to be a preponderance of suggestion that the sun radiates more at sun-spot maximum, although there are not wanting many who hold precisely the contrary opinion.

#### METHOD OF DETERMINING THE SUPPOSED VARIABILITY OF SOLAR RADIATION—SOLAR ACTINOMETRY.

It would seem, at first sight, a simple thing to show whether the sun radiates more at one time than at another by a direct exposure of a suitable actinometer during a term of years. This has been done in several instances, but so far as I know with a wholly unconvincing result. About twenty years ago, for instance, two able gentlemen reduced, independently, such a series of observations extending over a sun-spot cycle and deducted, the one that the sun's rays were appreciably more intense at sun-spot maximum, the other the exact opposite. Nor are later results with the most perfect apparatus more convincing.

\* \* \* From observations extending back to the year 1883, taken at Montpellier, with the Crova self-recording actinometer, an instrument of highly approved construction and most ably and honestly used, large fluctuations in the curve are evident, but any connection between them and the 11-year sun-spot period, whose maxima occurred in 1883 and 1894, is hard to recognize.

#### EFFECTS OF ATMOSPHERIC ABSORPTION.

Shall we then conclude that the negative of the question is proved and that the solar radiation does not vary to any considerable extent periodically along with the presence of spots upon the surface of the sun? This conclusion would be premature. The observer at the earth's surface sees the sun much as a fish at the bottom of the lake sees the clouds. More than one-half of the sun's radiation which reaches the outer layers of the earth's atmosphere is reflected or radiated away or is absorbed within the atmosphere and falls wholly to reach the earth's surface except as heat produced by absorption and communicated chiefly by convection and precipitation. The atmosphere is constantly varying in its transparency. These changes are chiefly caused by water vapor, water globules, and dust becoming more or less abundant, and are so great that even the largest depressions in the curve of actinometer results just referred to might easily be thus caused. Indeed, it occurs to me, and may very likely have occurred to others, that the great depression in the curve for the years 1884, 1885, and 1886 was caused by the presence in the air of dust from the remarkable eruption of the volcano of Krakatoa in the summer of 1883.

In conclusion [Mr. Abbot remarks that], new views regarding the relation of the sun to meteorological phenomena point, like all their predecessors, to the complexity of the sun and the uncertainty of deductions based on our present knowledge. At the same time the probability of a vital connection between the solar changes and matters of great interest upon the earth has been more and more confirmed within the last thirty years. It would seem that satisfactory progress in our understanding of these relations requires that observations of the energy of the solar spectrum be carried on at the highest practicable altitude in or near the Tropics for a term of years that shall not be less, but prefer-

ably more, than a complete sun-spot period of eleven years. Such an investigation would determine, it may be hoped, whether or not the sun emits different quantities of radiation in different years; whether observations at lower altitudes may be relied upon to follow the sun's condition; and it might also throw light on the cause of solar periodicity.

In the Transactions of the Toronto Astronomical Society for the year 1901, Prof. R. F. Stupart, director of the Toronto Observatory, discusses as follows investigations regarding the relations that may exist between sun spots and precipitation, as indicated by observations taken at Toronto and neighboring stations from 1830 to 1901:

In order to test whether any probability of a connection existing between sun-spot periods and precipitation is indicated by the records of Toronto and neighboring stations, the writer has charted the sun-spot curve from 1830 to 1901, and also a precipitation curve obtained from the annual amount registered in the Lake Ontario basin. Between 1830 and 1842 an approximate value for the precipitation has been obtained from the records of Rochester and Marietta; from 1843 to 1860 the complete records at Toronto and Rochester, together with broken series at Buffalo and Oswego, have been used. From 1861 to 1873 continuous records at Toronto, Buffalo, Oswego, and Rochester were available. For the period between 1874 and 1901 Woodstock and Kingston, Ontario, were also considered. The sun-spot curve is that by Mr. William Ellis, F. R. S., published in the Proceedings of the Royal Society, March, 1898, volume 13, page 78.

The sun-spot curve had been doubled in those years that the precipitation exceeded the average mean amount of the whole series. Finally the + sign was placed opposite the years of greatest precipitation in each sun-spot period and the — sign opposite the years of marked deficiency. The result obtained is apparently instructive, as the combined sun-spot and precipitation curve seems to indicate a precipitation larger than normal for the two or three years immediately following the sun-spot minimum, and another pulse, less pronounced and more irregular, about midway between maximum and minimum; the sign + was found in every instance either at the sun-spot minimum or within three years following, and — signs were in each case found at sun-spot maximum or within two years of it, and again just previous to the minimum.

Summing up these results it would appear that in the Lake Ontario basin the precipitation is likely to exceed the normal during two or three years immediately following the sun-spot minimum and again about three years after the maximum, and that it is likely to be somewhat less than normal about sun-spot maximum and during a few years preceding sun-spot minimum.

As a close connection probably exists between precipitation and the movements of high and low pressure, and, indeed, between precipitation and mean pressure values, as a preliminary investigation, the movements of low areas during the months of December and March in each of the years between 1873 and 1901 were tabulated, the total number in each year being divided into groups comprising those areas which were first observed in the northwest States or Territories; those which were first observed in the western States and those which were first observed in the southwest States or Gulf of Mexico; percentages showing the relative frequency of the areas in the various groups in each of the months of the whole period under consideration were thus obtained and a curve drawn. A very evident maximum of southwest areas in December is shown in 1873-79, 1884-85, and 1894-95; and for March in 1876-1878, 1883-84, 1890-1892, 1897-1900. On plotting curves showing percentages of areas other than from the

northwest States and Territories, it would seem that the March curve is very nearly the reverse of that for December. Corresponding curves for June and September are in course of preparation, and subsequently all months of the year will be considered.

It is conceivable that a varying solar heat radiation during a sun-spot cycle may cause appreciable changes in the movements of high and low pressure areas, changes perhaps largely influenced and governed by a fluctuating intensity and position of the subtropical belt of high pressure in corresponding seasons of different years. While the curves already plotted seem to indicate a connection between annual precipitation and sun spots, it is quite possible that a comparison of the corresponding seasons during several sun-spot cycles may show a much more evident connection between sun-spot and meteorological phenomena. Possibly a contraction of the subtropical high during sun-spot minimum may tend to a more than average number of low areas developing in the Southwest while the sun is south of the equator and a diminution in the number and intensity of storms during the warmer seasons when the sun is north.

#### STELLAR INFLUENCES AND PLANETARY METEOROLOGY IN LONG-RANGE WEATHER FORECASTING.

The long-range weather forecasts of the ancients, that have in modern times been referred to by uninformed persons as one of the lost arts, consisted merely of an association of the seasons with the

appearance of certain heavenly constellations, and the extent to which seasons were favorable or unfavorable to agricultural or other pursuits fixed the beneficent or malevolent character of the influences that were ascribed to the stars with which they were identified. During the last few hundred years, however, or since the establishment of the sun as the dominating body of the system of which the earth is a part, and since exhaustive tests have shown that the influence of the stars on the phenomena of the earth's atmosphere is practically inappreciable, no serious attempt has been made, even by so-called long-range weather forecasters, to ascribe to the fixed stars a causative influence on terrestrial weather.

Modern advocates of the ancient art of star divination, or astrology, now form a class of fortune tellers whose success depends, as it did thousands of years ago, upon a more or less deeply rooted inherent belief in the superstitions that find lodgment in the average human breast. Trading upon this belief certain men write and talk learnedly (?) and wandringly regarding eclipses, occultations, and various planetary combinations, accounts of which they cull from almanacs, and ascribe thereto, for a pecuniary consideration received from a credulous or ignorant and unobserving constituency, influences and effects upon our weather that are absolutely hidden and undiscoverable by any known method or system of examination or comparison. These facts regarding alleged planetary influences are presented with an unimpaired belief that they will not in the least weaken the inherent yearning for the mystical referred to, that leads men to subscribe literally and liberally to the support of artful assumers of superhuman knowledge.

Meteorological literature is deficient in references to planetary influences on the weather, and from this fact it may be assumed that long-range forecasters fear to enter a field where deductions are subject to mathematical demonstration, and where claims of superior knowledge will be confronted by established or recognized facts pertaining to the more exact science of astronomy. There are of a necessity exceptions to this rule, and the plea for entering the field is invariably an assumption of knowledge that is universally recognized as being beyond the present scope of astronomy.

In concluding remarks under this head it may be stated that while there is no evidence that the planets of the solar system have a direct controlling influence upon terrestrial weather, arguments have been presented to the effect that they are factors in the production of sun spots and may be, therefore, indirectly and distantly connected with variations in barometric pressure and magnetic force. The connection has not, however, been established; and however fascinating the vision of forecasting possibilities that would result if a knowledge of

the relation of the weather to sun spots could be supplemented by exact calculations of the existence of causes that produce sun spots, the fact that the former connection has not been determined necessarily points to a concentration of effort to solve the first step before advancing to the second step in this extremely complex problem. And it is in the complexity of the problem that long-range forecasters find a refuge. They possess a degree of acumen that enables them to avoid explanations of methods and results along lines where demonstrated explanations are not possible, and to resort to vague references regarding disturbing and imperfectly understood planetary electrical influences, apexes of planetary disturbances, etc., when called upon to explain failures in the operation of their alleged systems or to reply to inquiries regarding the basis upon which they are made.

#### WEATHER INDICATIONS AFFORDED BY ANIMALS, BIRDS, AND PLANTS.

Observations of the habits and conditions of animals and birds and the appearance of plants have a recognized value in determining the character of past weather and, to a limited extent, the weather for a few hours in the future. In a state of nature the condition of animals and plants is an indication of the character of past weather, so far as it has affected their physical condition in the one case and their growth and preservation in the other. The appreciation of animals and plants for future weather must necessarily be limited to the effect or influence upon their organizations of present atmospheric conditions, and in the case of animals the sensations that are produced by certain conditions or variations of atmospheric moisture, pressure, temperature, etc., are instinctively associated with the kind of weather that usually follows the kind of sensations experienced. Neither animals nor plants can possibly be affected by the weather of a future month or season.

Undomesticated or wild animals, fowl, and birds are usually used as an observational basis for long-range forecasts. Animals, such as the ground hog, or woodchuck, and the bear, that make winter a season of hibernation, are supposed, by the character of their preparations and the time of their retirement, to indicate the length and strength of the cold of the approaching winter, and toward winter's close they again become prominent factors in this scheme of forecasting. For, according to weather folklore—

If, on Candlemas day the weather is bright and clear, the ground hog will stay in or return to his den, thus indicating that more snow and cold are to come (and there he stays for a period that varies in length in the different sayings that relate to this act from two to six weeks); but if it snows or rains he will creep out, as the winter is ended.

The bear comes out on the 2d of February, Candlemas day, and if he sees his shadow he returns for six weeks.

If the sayings regarding the coming out of the ground hog and the bear on Candlemas day possess any merit, it rests upon the fact that fine and clear days in the early part of February are usually cold days, and that cloudy weather at that season is likely to prevail during warm days. The animals in question therefore consult their own comfort in cases where they make a premature exit from winter quarters. If it is cold they return; if it is not cold they remain out until the inevitable return of cold weather, which at that season will not be delayed many days.

The thickness of the fur of fur-bearing animals is also used as evidence of the character of the approaching winter, when, as a matter of fact, this depends absolutely upon "the physical condition of the animal, and his physical condition depends upon the weather of the past and the extent to which it has affected his food supply and general health, rather than upon the weather of the future."

The accumulation of food by squirrels, beavers, and other animals during the autumn months is also taken as a guide to the character of the coming winter. It is assumed that the gathering of a large supply of food indicates a long, hard winter, and vice versa. Careful observations of the habits of animals show that the autumn habits referred to or their omission bear no relation to the character of the following winter. The quantity of nuts stored by squirrels is governed by the supply of nuts at their disposal. In seasons when the crop is abundant the busy little animals will gather a large quantity, and when nuts are scarce his accumulation will be correspondingly small. The supply of nuts is governed by past and not future weather.

Birds of passage migrate to the south with the first breath of winter, or when their food supply is affected by inclement weather that is peculiar to approaching cold weather, and return north when spring sets in in the south. That their flights are influenced by present rather than a knowledge of future weather conditions is evident to all observers. Their judgment is on a par with that exhibited by some men in doffing or donning winter clothing; their actions are dictated by a sense of personal comfort, and they are often compelled by actions to admit their error. The thickness of plumage on wild and domestic fowls is also a result of feeding and past conditions of weather, rather than an indication of the character of future weather. And the goose-bone theory is one on which no two geese agree.

Moss, bark on trees, and the thickness of nut shells, pumpkin rinds, etc., furnish another basis for long-range weather speculations that also confuse and misinterpret conditions that are due to past conditions and have no bearing on future weather. There is one feature of tree weather forecasting, however, that possesses merit in so far as it presents as a basis a record of the general character of the weather for



many years, and may thus show or indicate recurring seasons of certain kinds of weather. Trees of great age and large growth, like the sequoias, indicate by their rings years that have been favorable and unfavorable for their growth, or, in other words, wet and dry years in the region in which they are located, and thus establish a record of the seasons that may be useful in calculations for the future.

In passing, it will be noted that prominent advocates of this branch of long-range weather forecasting have long since disappeared from public view, which fact may be taken as indicating that dishonest practices can be profitably conducted only by the possession, or an assumed possession, of superior knowledge, or under a cloak of mysticism, and not in connection with matters concerning which ordinary observation will reveal the truth.

#### ESTIMATES BASED UPON DAYS, MONTHS, SEASONS, AND YEARS.

There are several valid reasons for assuming that the weather observed on certain days may indicate the character of the weather for certain subsequent days. The first of these is that in the middle latitudes of the globe well-defined atmospheric disturbances or general storms of greater or less intensity average about one in each six or seven days; the second, that marked departures from the average weather occurring on one day, or on two or three consecutive days, are likely to be balanced by reverse abnormalities in the near future; and the third, that the general average duration of warm waves and cold waves, which are attendant features of areas of high and low barometric pressure, is three days. The seven-day period also corresponds closely with the moon-phase periods, which admittedly have a slight effect upon rainfall (too slight, however, to be considered in daily forecast work).

The assumed or supposed six or seven day period of recurring weather is indicated by the common saying, "If it rains on the first Sunday in the month it will rain every Sunday in the month." This saying possesses value in so far as the weather may conform, in particular instances, to a general average, and the likelihood of the weather conforming to this extent to general averages is not sufficiently great to justify the employment of the chance in actual forecast work. Forecasts for two to three days in advance, made in the full light of present knowledge, must be based upon actual existing atmospheric conditions that prevail over great areas, and they represent calculations of changes that will occur within the areas; they deal with average conditions only so far as a recognized tendency on the part of the weather to return to average conditions may be considered. Sunday was doubtless selected, in the saying quoted, for the reason that the weather and its seasonal or unseasonal character is more closely observed and studied on certain days, notably on Sun-

days and holidays, when men's minds are not occupied with their usual pursuits; any other day in the week will answer as well for this form of estimating the weather of the future.

Long-range weather forecasters, for purposes of mystification, attribute the six and seven day period to the moon's influence. They time their disturbances six or seven days apart, start them on the Pacific coast and carry them by regular stages across the United States, assuming in each case a conformance to general averages. Equal accuracy or inaccuracy in the forecast would result if they started the disturbances in the central valleys or on the Atlantic seaboard on corresponding dates, or introduced them on the Pacific coast on dates intermediate to those they select. By claiming, for verification purposes, a day or two on either side of the dates specified, by carefully avoiding specific forecasts of rain for specified days and districts, and by calling attention to hits that will occasionally be made under any system of chance, and never referring to misses, they successfully pursue in these enlightened times the practices of the fabulous age.

The six and seven day weather periods have been subjected to a rather searching examination by H. Helm Clayton, and the results of his examination are given in several publications, but principally in the *American Journal of Science and Art*. It may be noted in this connection that Mr. Clayton for a time actually published forecasts based upon his conclusions, which were not, apparently, satisfactory as regards results nor convincing as regards a confirmation of any theory he may have held.

Investigations and conclusions based upon honest and thorough examination and comparison of meteorological records show that generally recognized, though ill defined, six and seven day periods of recurring weather can not be utilized for making definite forecasts for specified days and localities. Assuming that forecasts of rain or fair weather, warmer or colder, based upon the results, would yield a slightly higher verification than unqualified guesses—which, if made in sufficiently large numbers, would naturally verify in one-half the cases—there is no evidence presented by the investigations that the character or intensity of the disturbances that attend the barometric minima can be determined. A knowledge of the probable order of succession of barometric depressions for periods of one to four weeks in advance would greatly assist the forecaster, and as a matter of fact the probability of the succession has been given due weight and consideration by the Weather Bureau for many years. Experience in actual forecast work has shown, however, that rules that are subject to 50 per cent of exceptions are, like theoretical deductions, dangerous factors to employ in the work of weather forecasting. And aside from conclusions that have been or may be reached regarding systems or methods of forecasting merely weather and temperature,



the fact remains that forecasts of this class are of small importance when considered in connection with forecasts of severe storms, etc. In fact, the value of weather forecasts is fixed by the degree of accuracy that is attained in predicting gales, cold and warm waves of marked severity, heavy snow, heavy rain (and floods resulting therefrom), frost, and other atmospheric phenomena of an unusual or exceptional character, and long-range forecasts that are calculated to be of special value to commercial and agricultural interests must specify these occurrences for specified sections, and to this end honest endeavor is being directed.

| A casual examination of published long-range weather forecasts shows clearly that the success of the systems depends absolutely upon a conformance of the weather to six or seven day periods with modifications called for by seasonal averages and chances, and the fact that in about 50 per cent of the cases the periods are not revealed and that fully one-half of the forecasts are misplaced in the periods that do appear proves to conservative minds the unsoundness of the systems. It is apparent from reports of investigations that have been made that there is a tendency on the part of investigators to assume the six and seven day periods and to then endeavor to fit the periods to moon phases or positions, solar rotations, etc.

Estimates of future weather that are based upon the character of certain days have their origin in fancy or superstition. As a rule the days selected are church or saints' days or holidays, and it is apparent that the selections have been governed by the prominence of the days. As a basis of calculation the weather of certain days is of value—

only so far as it may be assumed that normal weather conditions on those days are favorable and abnormal conditions are unfavorable for seasonable weather in the near future. They may be considered as indicating which way the balance of temperature and precipitation tips at that particular season of the year, and the forecasting feature is found in the statement of weather conditions that will be required to adjust the balance.

Individual months are taken as a basis of prediction for succeeding months or seasons, and all estimates of this character that possess merit speculate merely on normal tendencies of the weather at certain seasons, and, like estimates based upon the character of days, assume that normal conditions are favorable and abnormal conditions unfavorable for seasonal weather in future months, seasons, or years. In fact, the entire scheme of long-range forecasts that are based upon the condition of the weather during certain periods, whether long or short, depends upon an assumed inviolable law of compensation. This assumption is, in a degree, justified, but for purposes of specific forecasts it possesses little value. Records of meteorological observations taken at given points show that the temperature and rainfall of single years and series of years conform closely to normal values and that

the greater the period the smaller are the departures. Conversely, the shorter the period the greater the departures that are sometimes shown, until for periods of a month or less it is impossible to calculate to what extent abnormal features may predominate. There is a popular impression that a warm winter will be followed by a cool spring or summer, and a hot summer by a cool autumn or winter, but the succession so indicated will not occur in more than 50 per cent of any large number of cases that may be noted. The question may here arise, How, then, can compensation be made for extreme abnormal conditions for days, months, or seasons? The answer is that it is not necessarily made in any one month, season, or year. For instance, in the Middle Atlantic States the summers of 1901, 1902, and 1903 were cool, and the winters of 1900-1901, 1901-2, and 1902-3 were moderate, while the winter of 1903-4 was probably the coldest in the history of that section. The question now arises, What period in the preceding three years could have been used as a basis for forecasting an exceptionally cold winter in 1903-4?

Examinations of records show that excesses or deficiencies of temperature or rainfall in any season do not necessarily indicate opposite excesses and deficiencies for any given future period, and that when compensation is made for excesses or deficiencies it is made gradually and almost imperceptibly as often as in the form of marked opposites.

#### PREDICTIONS BASED UPON OBSERVATIONS OF OCEAN CURRENTS.

The influence of ocean currents, notably the Gulf stream and the Japan current, upon the weather and climate of western Europe and western North America, respectively, has been discussed in numerous papers, and the belief has been expressed that observations of variations in the Japan current could be made a basis for forecasting California weather for several months in advance. The opinion has also found expression that the course of the Gulf stream, with particular reference to its north and south shifting over the western Atlantic, had a controlling influence upon West Indian hurricanes and even furnished a basis for predicting their periods of frequency and intensity.

The general subject of ocean temperatures and meteorology, based upon a paper by Sir John Murray that appeared in the *Geographical Journal* for August, 1898, published by the Royal Geographical Society of London, is considered, in brief, in the *Monthly Weather Review* for July, 1898. After summing up data of ocean temperatures and comparing these temperatures with those obtained over the continental areas, the editor of the *Review* concludes as follows:

At first thought one would expect to find in Doctor Murray's lines of equal annual temperature range some traces of the course of the Gulf stream and Kuroshiwo (Japan current), but it is only the changes in the positions of these

currents that can produce ranges of temperature, and these changes are so largely controlled by the wind that Doctor Murray's charts show us principally the effect upon the ocean water of the changes in the atmospheric circulation. This same principle applies also to the closed seas, such as the Mediterranean and Baltic, the Red Sea, and the Persian Gulf, in all which cases a larger range of temperature is observed at the head of the sea than at the mouth of the sea, due to the fact that the highest temperatures occur at the head when the wind blows toward that direction in the summer, and the lowest temperatures when the wind blows in the opposite direction at the opposite season of the year. There is, therefore, in this map no comfort for those who maintain that the Gulf stream or the Kuroshiwo, respectively, alleviate or control the temperatures of the eastern portion of the Atlantic and Pacific oceans and the adjacent portions of Europe and America, respectively. Everywhere we see that it is the wind that controls the temperature of the surface of the ocean, and then carries this ocean temperature inward over the land. The same applies to the Southern Hemisphere, where Doctor Murray's chart shows that the greatest range of ocean temperature is in the regions where there is the greatest annual range of wind direction.

In the August Review of 1898 Professor Abbe refers as follows to studies of the Japan current:

We notice in several California papers earnest articles advocating the study of the Japan current and its relation to the weather of the Pacific coast. Especially does Mr. W. S. Prosser, of Auburn, Cal., state that in 1878 or 1879 he suggested this very thing and urged favorable action on the authorities at Washington.

It ought hardly to be necessary to assure the citizens of the Pacific coast that the Japan current, like the Gulf stream, has been studied with much care by the navigators of all nations, and charts have been published showing the temperature and the movement of the surface water, not only for these special currents, but for the whole of the surrounding ocean for each month in the year. These charts show that without any doubt whatever the currents as such soon dwindle away, and all that is left is a very slow movement of the water to and fro with the wind. It is the west wind that strikes our Pacific coast, and not the Japan current. This wind brings moisture from the Pacific Ocean, and not from the neighborhood of Japan. It is these moist winds, and not the ocean currents, that control the climate of California.

The hydrographic offices of all nations are engaged in the study of ocean currents and surface drifts as such, including their dependence upon the winds. The meteorologist studies the winds as affected by the surfaces of the land and ocean, but he finds the atmosphere moving so rapidly and its various portions so easily intermixed with each other that it is at present impossible to tell whether the moisture brought by the wind to California comes from the Pacific Ocean in general or from the Japan current especially. In fact, it matters little to him where it comes from. He has to take it as he finds it over California, and then decide whether it is rising and cooling to form cloud and rain, or whether it is descending and likely to stay unprecipitated. The important features of the weather of California depend principally upon whether its winds are descending and being pushed outward from a high and dry area to the northeastward, or whether they are descending and coming from moister air to the northwestward. It is the air supplied from the high-pressure area on the southwest, between California and Hawaii, that gives the former her long-continued spells of dry, clear weather. The length of these spells may

depend, in a general way, upon atmospheric conditions, not on the condition of the ocean.

In the fall of 1898 the writer remarked on the Japan current as a controller of California weather as follows:

The subject of long-range weather forecasts has recently gained attention by reason of a suggestion of Professor Hammon, of the Weather Bureau office at San Francisco, that possibly the character of the seasons in California can be successfully forecast by a study of the Japan current.

In examining reports of meteorological observations made in the Aleutian Islands he discovered an apparent relation between abnormal air temperatures in those islands and periods of drought and excessive rainfall in California. He associated unusually high temperature in the north with subsequent periods of drought in California, and unusually low temperature in the north with excessive rains in California. In seeking an explanation of these apparent relations he concluded that periods of high temperature in the Aleutian Islands indicated a northern course of the Japan current, whereby the heat of that current was, in part, lost, causing it to arrive off the California coast possessed of unusually low temperature, giving drought in California; and that abnormally low temperature in the Aleutian Islands indicated a southern course of the Japan current, which, in following this course, retained its heat and arrived off the California coast possessed of unusual warmth, thereby causing excessive rains in California. He calculated that if the succession of these conditions could be established by further observations, three months' foreknowledge of the character of the weather in California could be given and that the fruit and grain industries of that State would be benefited by the forecast to the extent of millions of dollars annually.

Professor Hammon's merely preliminary investigations, and the theory which has evolved from them, naturally lead to the question, Can long-range forecasts of California weather be based upon observations taken along the Japan current? The solution of this question is dependent upon the establishment of the following facts: That there are periods during which the water of the ocean off the California coast is unseasonably warm or cold, that these periods are associated with periods of excessive rains or drought, respectively, in California, and that periods of warm and cold ocean temperature and of excessive moisture and drought in California are associated with periods of abnormally low and high air temperatures at points in the north which border the course of the Japan current.

As regards the first fact to be established, there are no known data which show that the temperature of the ocean water off the California coast is subject to unseasonable or abnormal changes in temperature; and we are not permitted to associate possible but unknown changes of this character with California climatic changes, nor with abnormal air temperatures over the Aleutian Islands. We are, in fact, confined to an attempt to associate periods of unusually high and unusually low air temperatures over the Aleutian Islands with periods of drought and excessive rains in California. Owing to very meager data it is not possible to establish these relations; it is not possible to

say whether the apparent relations discovered by Professor Hammon were accidental or resulted from a law of nature.

In the Philadelphia Press of October 5, 1898, Mr. Harvey M. Watts remarks upon the deductions of Mr. Hammon regarding the influence of the Japan current on California weather as follows:

The Weather Bureau has had the question of long-range weather forecasts once more brought to its attention by the California State Board of Trade. Every once in a while the problem and possibility of seasonal forecasts is discussed but to be negatived by present knowledge. That an approximately correct seasonal forecast would be of enormous benefit to agriculture is unquestioned, and it is this that impels the Californians to ask the Government experts to look into the matter, for they believe that the observer at San Francisco, Mr. W. H. Hammon, has discovered the determining factor in the seasonal variations of California weather. With this factor known and its variations recorded the possibility of forecasting wet and dry years opens up a new future for agriculture, as it reduces useless experiment and heavy losses due to climatic vagaries.

The seeming fact that has been worked out by Observer Hammon is that there is a close connection between the shifting of the Japan oceanic current and the wet and dry seasons along the Pacific coast. When the Japan current is deflected to the north, according to Mr. Hammon's theory, it gives up its warmth to those regions and arrives off the Pacific coast cooled down to such a degree that little evaporation results and the year is dry. If the current keeps moving along the lower latitudes its effect is felt in the increased warmth, moisture, and precipitation along the lower Pacific coast line and a wet year is experienced. This relation, as determined by Mr. Hammon, takes three months to show its effects, so that the Californians believe that a cable laid to one of the Aleutian Islands would enable the United States observer at San Francisco to forecast the summer conditions for California by a study of the spring conditions 2,000 miles to the northwest. In this way millions might be saved by means of a general seasonal forecast, which would enable agriculturists to prepare for the worst or make ready for a bountiful return under favorable weather conditions.

Without going into the merits of Mr. Hammon's deductions for the moment, it should be said that extended observations either with or without a cable in the Aleutian archipelago will well repay any outlay the Weather Bureau may ask Congress to make. Not only the Pacific coast weather, but the seasonal conditions of the entire Northwest, the upper Mississippi Valley, and, to a certain extent, the watershed of the Great Lakes are forecast in the conditions that prevail in the northern Pacific Ocean. It is from the northern Pacific that the continental storms move in that play so important a part in the climatology of the United States. And it is the shifting of these oceanic areas of low barometer relatively to the high barometer over the interior of the continent in British America that makes up the alternations of warm and cool, wet and dry weather that are daily displayed on the United States weather maps. To attribute the variations of climate due to these great atmospheric swirls to an oceanic current, however, seems an error, though it is the same kind of an error that for so many years attributed to the Gulf stream a determining effect on the climate of all western Europe. As the results are out of all proportion to the cause, the Gulf-stream theory has been generally abandoned, and it would seem that Mr. Hammon's Japan-current theory would suffer a like fate, for it is the general eastward atmospheric drift and not the trend of the oceanic currents that determines the climate.



However, even if one throws overboard the Japan current, it does not in the least destroy the possibility of forecasting weather conditions in the United States by means of observations in the Aleutian Islands. There our weather is brewed. There the great changes occur—the deflection of the Japan current probably being an incident—that are felt later on our coast and continent. To study them, to discover any rhythm in their yearly or secular variation, is to get at the secret of long-range forecasting. This work is one of vast importance, not only for California but for the greater part of the United States, where the weather is controlled by the circumpolar circulation. To make sure, however, of the accuracy of these seasonal forecasts a wide outlook must be maintained. In India, the only country where such forecasts are attempted, the atmospheric conditions over Persia, southern Africa, and Australia play an important part in drawing conclusions. For us it must be the northern Pacific and the Athabaskan region. And to get at the former let us have the Aleutian stations by all means.

In a letter dated February 19, 1904, the honorable Secretary of Agriculture answered a communication of Mr. W. S. Prosser regarding the importance of investigations of the influence of the Japan current on the weather of the Pacific coast of the United States as follows:

Your letter of the 8th instant, urging the importance of studying the influence of the Japan current upon the weather conditions of the Pacific coast, has been received and given careful attention. You are quite right in your statement that an accurate forecast of the rainfall of California a season in advance would be extremely valuable to the people of that State. I can not assent so readily, however, to your second proposition, viz, that the climate of the Pacific coast depends upon the Japan current, as that of England depends upon the Gulf stream. Persons who have given the matter careful study and should, therefore, be in a position to speak advisedly are not willing to admit that either the Gulf stream or the Japan current, as such, exerts any appreciable influence upon the climate of the shores opposite its origin. It is quite true that the general oceanic influence is a powerful one on the shores of western Europe and western America. The popular error in regard to the matter is twofold in its nature. In the first place, the public generally has a very inadequate idea of the true nature of both the Gulf stream and the Japan current. The mistake is generally made of giving both of them throughout their entire course attributes which they possess only at and near their origin. In the second place, the popular mind ascribes to the two currents under consideration, which form only a small part of the great oceans in which they course, effects which truly belong to the oceans as a whole and not to an insignificant part of them. Within the last half century organized effort has been put forth in various parts of the world to obtain accurate data as to the weather conditions and currents of the great oceans.

Out of all this effort has come certain facts that satisfactorily explain the broader principles of oceanic circulation. First and foremost of these is the effect of the wind upon the ocean waters. Throughout a broad belt on the earth's surface, say from twenty degrees south latitude to thirty degrees north latitude, the winds are persistently from some point in the eastern semicircle, and it is in this region that the great oceanic currents have their origin. In the Northern Hemisphere the surface waters, under the influence of the northeast trade winds, have a decided set from the northeast or east, and there is formed what is known in both the Atlantic and Pacific oceans as the north equatorial

current. This current, or drift, as it might be called, is due to the direct action of the wind on the water. In the North Atlantic the surface drift from the northeast heaps up the water in the Caribbean Sea, and since it can not escape to the westward the overflow is forced to the northeastward through the Florida Straits, and thus forms the Gulf stream. This stream, as it emerges from the Gulf of Mexico and passes northward between Florida and the Bahamas, is only indirectly caused by the wind. In its lower reaches the wind is powerless to change its direction, but it may, and often does, accelerate or retard its velocity. In the North Pacific Ocean the north equatorial current impinges on the eastern shores of Formosa and adjacent islands, the greater portion, however, passing into the China Sea. The remaining portion is deflected northward along the eastern shores of Formosa until it reaches about twenty-six degrees north latitude, where it bears off to the north-northeast, washing the southeastern shores of Japan and then moving northeastward with diminishing velocity it merges with the general easterly drift of the North Pacific.

The existence of the so-called Japanese current in the North Pacific is perpetuated during the season from March to September by the prevailing southwesterly winds, but when these fail, as in the months of October to February, the current as such becomes uncertain and variable, its direction and velocity depending largely upon the wind experienced from day to day. I have entered into this detail in order to make clear that the great ocean currents are created primarily by the wind, and that in themselves they can not have the dominating influence on the weather that is often ascribed to them. The influence of the Pacific Ocean on the climate of California is, of course, understood. It tempers the winds of winter and protects a large portion of the State from frosts and snows normal to the latitude, and in summer the moist, cool winds bring cloud and fog along the coast, and this it does from year to year without perceptible change. The great ocean itself, with its thousands of miles of water surface, is the important factor as regards the climatology of the State. The temperature of the ocean waters changes but little from year to year; whatever slight variation there might be in the temperature of the so-called Japan current would not, it is believed, have the slightest effect on the rainfall of California a year hence. I do not underestimate the value of seasonal forecasts, nor am I unwilling to set on foot investigations that give promise of even a small degree of success. The progress of science is necessarily slow, but let us continue to hope that the problem may be eventually solved.

For further information relative to the effect of the oceans on land climates you might read an article by Professor Moore, Chief of the Weather Bureau, in *Encyclopedia Americana*, a publication just now coming from the press.

#### A CONSIDERATION OF ATMOSPHERIC PRESSURES IN WEATHER FORECASTING.

Many well-informed meteorologists are of the opinion that the next advance in the art of weather forecasting will be accomplished by a correlation of the greater and lesser areas of high and low barometric pressure of the Northern Hemisphere or of the globe. The forecasts now issued by meteorological services are based upon skill acquired by study, observation, and experience in calculating the development, movements, increase, and decrease in intensity, and magnitude of areas of high and low barometric pressure that appear within areas covered by the telegraphic reports of the several serv-

ices. The dependence of these lesser high and low areas upon the greater or continental and oceanic so-called permanent areas of high and low barometric pressure is recognized, and the fact is admitted that a knowledge of the character and movements of the greater masses of the earth's atmosphere, as represented by the continental and oceanic seasonal high and low areas, is essential to calculations of weather conditions in any given section or locality for periods greater than two or three days in advance. For it is apparent that upon the exact location and magnitude of these greater high and low areas for a day, week, month, or season does the character of the weather in the regions they dominate depend. For instance, a slight shifting to the westward of the summer North Atlantic high area gives unusual heat and generally dry weather over the eastern portion of the United States. If the center of the high area shifts to the westward south of its usual position, as regards latitude, the heat is general from the Gulf of Mexico to Canada; if the center occupies a more northern latitude in its western position the heated area is confined to the more northern districts of the eastern portion of the United States, and the South Atlantic States receive the benefit of easterly winds from the ocean. When the Atlantic high area occupies an easterly position over the ocean, or exhibits pressures below the normal, cool weather for the season, or at least variable temperatures, are experienced over the eastern portion of the United States. In fact, the North Atlantic high area controls to a great degree not only the summer weather of the greater part of the United States, but also the course and character of West Indian hurricanes.

Winter types of weather over a great part of the middle circuit of the Northern Hemisphere are undoubtedly dominated in a greater or less degree by the great Asiatic area of high barometric pressure. In the middle latitudes the movements or swingings of this vast mass of air is to the westward; when it moves or extends over the northern portion of Europe North Atlantic storms are likely to be deflected toward southern Europe, and cold, stormy weather is experienced over southern European countries; when it extends westward over southern Europe North Atlantic storms follow a course toward the Scandinavian coast, and moderate temperatures are experienced in central and southern Europe. When the great continental high area extends westward over west-central Europe and the British Isles it checks the succession of North Atlantic storms, and finally affects the rate of progression of high and low areas over the United States. In its normal winter distribution atmospheric pressure is higher over southern Europe and relatively low over the northern, and especially over the northwestern countries. Under these conditions of atmospheric pressure the progression of storms from the Atlantic is normal; when, however, this arrangement of pressure is reversed or dis-



torted, abnormal storm movements and features will be observed. At times, also, when the air masses up over western Asia and continental Europe the advance of Atlantic storms is checked, resultant low barometric pressure prevails for periods of several days over and near the British Isles, high pressure builds up over the middle longitudes of the Atlantic, and the eastward progress of high and low areas over the United States is retarded. It has been found by observation that this retardation of the usual progression of high and low areas over the eastern half of the United States continues several days after evidence appears of a return to normal barometric conditions over western Europe.

The influence of the Asiatic winter area of high atmospheric pressure is recognized in all studies and calculations regarding Asiatic weather and climate. The spring and autumn monsoons of the southern countries of Asia are directly associated with the breaking up in the spring and the building up in the autumn of the great interior air mass, and a solution of the problem of forecasting the time and character of the monsoons rests upon the ability of the meteorologist to foresee the nature of the changes that occur in Asiatic atmospheric pressures.

#### OPINIONS AND DISCUSSIONS OF THE GENERAL SUBJECT OF LONG-RANGE WEATHER FORECASTS.

Under the title "Imperial meteorology," in *Nature* (vol. 69, pp. 537-538), recent progress in meteorology is discussed as follows:

Slowly, but still step by step, the science of meteorology progresses, and new visions are opened up which suggest bright prospects for future possibilities, but which also lay exposed the lost opportunities of the past. Like every other science, the modern methods of observation (or at any rate the chief meteorological elements) are nearly all that can be desired, but when it is required to revert to observations made more than thirty or forty years ago, how lamentably few are the records and how uncertain in many cases are their accuracy. Further, anyone who has had occasion to hunt up early series of observations of pressure, temperature, rainfall, etc., will have been struck with the common occurrence of breaks extending here and there for one, two, three, or more years. Nevertheless, it is little use crying over the past, but strenuous efforts should be made in the future to see that the needed observations should be secured.

The more the variations of the weather are studied the more is the idea strongly impressed on the investigator that these variations from year to year are not mere matters of chance, but are produced by a cause originating outside the earth's atmosphere, and with little doubt from the sun, naturally the prime factor and father of all the important weather changes.

His apparent daily journey round the earth, caused by the latter's rotation, is the origin of all the diurnal changes familiar to meteorologists.

The earth's journey round the center of our solar system is again the origin of all the other meteorological variations called seasons which pass through their phases in a year.

From year to year, however, these daily and yearly variations, although they preserve more or less their original variations as regards their lengths of period, change in amount sometimes to a very great degree and cause one to speculate on the probable kind of weather for the following year.

The view that these changes from year to year are due to the direct or indirect action of the sun has a very great degree of probability in its favor, since we know that this highly heated body is in an active state, as deduced by the numerous and varied solar phenomena that have been observed. Further, the periodicities deduced from long series of solar observations have added another link in the chain of evidence showing that the sun's heat must be constantly varying, a fact which it is necessary to prove before solar influence can be put forth as a possible source of the terrestrial changes.

It is the work of the now numerous magnificent meteorological institutions spread over the globe for each to gather into its own particular net the meteorological changes that are occurring in its own area, and by means of these facts to forecast what kind of weather may be expected either on the following day, week, or month, or as far ahead as possible. Many of these institutions for several years found that their own areas were too limited in extent to give them the necessary data for the work in hand, and so entered into a mutual compact with neighboring countries for the exchange of certain pieces of meteorological information.

The present stage of meteorological investigation has in the last few years indicated that even this mutual help of the neighboring countries, each working for its own immediate ends, is not sufficient for a satisfactory solution of world meteorology.

"The next development of weather study will almost certainly be in the direction of international or world meteorology and its relation to the phenomena of sun spots and terrestrial magnetism.

"World empire entails world duties, and one of these appears at the present time to be a study of meteorology from the imperial and not solely from the national or parochial standpoint."

In his annual report for 1903 Professor Moore, the Chief of the United States Weather Bureau, refers to the problem of seasonal forecasts for a year, as follows:

It is a difficult piece of science that is involved in the attempt to place the forecasts of the seasons for a year in advance upon a reliable basis, because it may be necessary to take account of several interrelated processes in nature which depend upon the circulation of the atmosphere of the sun and of the earth. The science of meteorology is not to be confined to the atmosphere of the earth, because the changes in the action of the atmosphere of the sun precede the variations in the earth's air, which finally culminate in a certain type of season. Thus, wet and dry seasons, warm and cold summers and winters, and all the other climatic differences first depend upon the persistence of special high and low areas of pressure in one locality or another; these go back to the circulation of the great currents in the atmosphere, which seem to surge back and forth from one side of the earth to the other, or from the oceans to the continents; finally, these currents may be due to the solar radiation, which itself changes with the output of energy from the interior of the sun.

Thus, meteorology is really a very closely allied but difficult branch of solar physics, and it ought to be studied with the aid of a fully equipped observatory devoted especially to such researches. On the sun we count up the number of

hydrogen flames or prominences seen on the edge of the disk from day to day, and, from a discussion of the thirty years' record in hand, they are known to vary strongly from year to year. Similarly, the faculæ and spots have their fluctuations in synchronous cycles, and these have been studied for many years. Furthermore, the sun emits energy in the form of radiant light and invisible heat, and by means of suitable spectrum observations the variable amount of this light, and especially the invisible heat, can be registered from day to day and from year to year. The result of these records is to indicate that the sun is in fact a great, variable star, and that terrestrial weather may change in close synchronism with it. There is yet another register of the energy emitted by the sun to be found in the variations of the earth's electrical and magnetic fields, which is perhaps the most sensitive of all, and certainly the most accessible to our measures. The newly discovered action of ions in the atmospheres of the sun and the earth, respectively, which are now believed to be the basis of the electrical and magnetic manifestations, is affording much information upon this obscure subject, and it is full of promise in practical investigations. Langley has announced that the invisible radiant heat energy, as measured in his bolographs, varies from season to season and from year to year. The passage of an eclipse shadow through the atmosphere changes the atmospheric magnetism and electricity in the same way that day and night modify them—by cutting out the sun's rays. In short, the entire field of cosmical processes forms a complex problem which especially concerns the meteorologist, and by him should be studied out for the benefit mankind, whose life and happiness depend so largely upon the weather.

The Weather Bureau is so far convinced of the importance of finding out the laws of this cosmical physics, by which alone the problem can be conclusively solved, that it has been thought proper to found a research observatory at Mount Weather, on the crest of the Blue Ridge Mountains, about 6 miles from Bluemont, Va., and equip it suitably for these investigations. It is evident that such an institution, having its beginning in the early years of the twentieth century, will have an increased usefulness as the years go by if it is organized according to the demands of the best science. It will require fine instruments and able students if it is to command the respect of the scientific world. The subject of solar physics has already grown to such proportions that the British Association for the Advancement of Science has set off a solar-physics section from astronomy and mathematics; the solar-physics observatory at South Kensington, under the able direction of Sir Norman Lockyer, is putting forth valuable results; the solar observations by the Italians for the past thirty years have become invaluable as a basis for these studies; the observatory at Kalocsa, Hungary, and that at Zurich are known to all students for their important publications. Less directly, several of the great astronomical observatories are deriving some of their most valuable discoveries in astrophysics, which is simply another name for stellar meteorology. Thus Potsdam, Paris, Lick, Yerkes, Harvard, and other institutions are working zealously along these lines and filling out the realm of human knowledge in a fashion undreamed of a generation ago.

It may be asked why, with all this wealth of material being secured in other places, it should be important for the Weather Bureau to enter upon these studies as well. The answer is simple. These observatories, for one thing, specialize along certain lines, and it is evident that there should be at least one institutions in the United States where these results are brought together and studied side by side, so that their combined result at any given time can be worked out harmoniously and correlated with the prevailing weather condi-

tions. Furthermore, the publications of these several observatories are issued from the press as much as two to four years after the observations are actually made, so that it is obvious that these late reports can have little value in practical forecasting. We have no intention to enter upon the advanced research problems which rightly belong to specialists, but rather to adapt to the uses of the meteorologist and the forecaster such portions of the well-known types of observatories as seem to be practicable for the immediate uses of the Weather Bureau.

Specifically the plan in mind contemplates the development of an observatory as indicated in the following statement:

(1) An observatory building is in process of erection at Mount Weather, which is well adapted as a school of instruction and for making observations of the ordinary kind with the common meteorological instruments, barometers, thermometers, wind and rain gauges, nephoscopes, theodolites, and actinometers. The first floor is for administration, the second for living quarters, the third for laboratories, and the roof for observing.

(2) Plans are being prepared for a plant adapted to generate large quantities of hydrogen for balloon ascensions, including a shop for the construction of balloons and kites. The ascensions will be limited to about 4 miles in height, our immediate purpose being to measure the temperatures and thermal gradients, which will enable us to construct daily isothermal charts on the two upper planes already described so as to provide isotherms as well as isobars on the high levels. It is proposed to make a complete series of ascensions first at Mount Weather, and afterwards in different portions of the United States, in order to observe the temperature conditions in all classes of cyclones and anti-cyclones. We may attempt some high ascensions, up to 10 or 12 miles from the ground, when our experience and other conditions warrant, but since storm movements are practically limited to the strata within 4 miles of the ground, the first group of ascensions will be to moderate elevations.

(3) It seems important to install a high-grade bolometer for measuring the invisible solar radiation, which is thought by some students to be largely responsible for the actual temperature of the upper atmosphere. Also a first-class spectro-heliograph is required for keeping a record of the solar prominences, faculae, and sun spots prevailing at the time of making our weather forecasts. These two instruments are the essentials of an efficient solar physics observatory, and would require the services of an able student of physics to bring out the best results and discuss them efficiently in suitable reports.

(4) These records should evidently be supplemented by an observatory equipped with modern instruments for observations in atmospheric electricity and in magnetism, and we note that a number of valuable new instruments have been invented in recent years which we can use. The special subject of this research is the behavior of ions in the atmosphere as forerunners of weather conditions.

Generally the idea is to bring together for study under one direction the most valuable and practicable observations having a direct bearing on the higher meteorology, which is now engaging the attention of many able physicists and astronomers. In this field are found the best examples of physical and mathematical problems, because it is nature's great laboratory. The atmospheric conditions at Mount Weather are superb, the site being 1,800 feet above the sea level, on a ridge overlooking the wide Shenandoah Valley to the west and the plains of Virginia to the east. An equipment at that place, such as is contemplated, will induce a great scientific activity and generate an intellectual atmos-

phere highly favorable to the best scholarship. The assistants in charge of the various lines of work will form a strong corps of teachers, who will instruct a new generation of men in the great problems of meteorology, which are destined to occupy the attention of mankind in an increasing ratio with the lapse of time. If the equipment be made up of the very best instruments and able students secured to use them, and especially if patience be manifested in allowing the data to accumulate and be studied in the proper way, an improvement in forecasting for America should be assured. This institution is to be planned for continuous work in the future, and it is not supposed that its effect on forecasting will be immediately manifest because of the difficulty and complexity of the problems involved. One thing is certain, that the founding of such a research institution is the true scientific way to provide for the future, in assurance that the natural difficulties will finally yield to human persistency and intelligence.

In a report to the international committee, Southport, England, 1903, Sir Norman Lockyer presented a most interesting review and discussion of the subject of simultaneous solar and terrestrial changes (*Science*, Nov. 13, 1903). He called attention to the fact that "there are many cases recorded in the history of science in which we find that the most valuable and important applications have arisen from the study of the ideally useless," and that "long-period weather forecasting, which at last seems to be coming into the region of practical politics as a result of the observation of solar changes, is another example of this sequence." After referring to the knowledge possessed by the ancients of changes in the sun, and to sun spots and a magnetic force which acts upon a needle, which seem to have been known to the ancient Chinese, he passes to more modern inquiries, that date from the times of Galileo and Kepler, which have furnished telescopic observations of the spots on the sun and revealed by spectrum analysis the chemistry of the sun and of its spots, and have also enabled us to study daily other phenomena, the solar prominences, which will in all probability turn out to be more important for practical purposes than the spots themselves.

He quotes from *Philosophical Transactions*, London, 1801, page 265, an article by Sir William Herschel, which is particularly interesting, not only by reason of the prominence in scientific history of the writer but from the fact that an association of the variation in sun spots with the price of corn and wheat has resulted in popular discussions of the suggestion and misinterpretations of the language and meaning of the author during a period of more than one hundred years. Although Herschel had but little observational data upon which to make comparisons between cycles in the solar changes and the prices of corn and wheat, his argument regarding the influence of the sun on vegetation and his inference that variations in the quantity of light and heat emitted from the sun that are associated with the appearance and disappearance of sun spots were favorable or unfavorable to vege-



tation have been given respectful consideration by succeeding generations of scientists. The article referred to is as follows:

The first thing which appears from astronomical observations of the sun is that the period of the disappearance of spots on the sun are of much greater duration than those of their appearance.

With regard to the contemporary severity and mildness of the seasons, it will hardly be necessary to remark that nothing decisive can be obtained. An indirect source of information, however, is opened to us by applying to the influence of sunbeams on the vegetation of wheat in this country. I do not mean to say that this is a real criterion of the quantity of light and heat emitted by the sun, much less will the price of this article completely represent the scarcity or abundance of the absolute produce of the country.

On reviewing the period 1650–1713, it seems probable from the prevailing price of wheat that some temporary scarcity or defect of vegetation has generally taken place when the sun has been *without* those appearances which we surmise to be symptoms of light and heat.

To those acquainted with agriculture who may remark that wheat is well known to grow in climates much colder than ours, and that a proper distribution of rain and dry weather are probably of much greater consequence than the absolute quantity of light and heat derived from the sun, I shall only suggest that those very circumstances of proper alternations of rain and dry weather and wind, etc., favorable to vegetation, may possibly depend on a certain quantity of sunbeams being supplied to them.

About 1870 and 1871, Doctor Meldrum, director of the observatory at Mauritius, concluded that the number of cyclones in the Indian Ocean and the number of wrecks which came into the harbor of Maritius indicated the number of spots on the sun; that, in fact, the maximum number of cyclones was associated with the maximum number of sun spots. In the West Indies Poey found that, as a rule, the maxima of storms fall from six months to two years, at the most, after the years of maxima of solar spots; that out of twelve maxima of storms, ten coincide with maxima of spots, and that out of five minima of storms, five coincide with minima of spots.

#### CONCLUSIONS.

A review of the foregoing remarks and opinions regarding the application of past and present astronomical and meteorological knowledge to the theory and practice of long-range weather forecasting leads to the following conclusions:

1. That systems of long-range weather forecasting that depend upon planetary meteorology; moon phases, cycles, positions, or movements; stellar influences, or star divinations; indications afforded by observations of animals, birds, and plants, and estimates based upon days, months, seasons, and years have no legitimate bases.

2. That meteorologists have made exhaustive examinations and comparisons for the purpose of associating the weather with the various phases and positions of the moon in an earnest endeavor to

make advances in the science along the line of practical forecasting, and have found that while the moon, and perhaps the planets, exert some influence upon atmospheric tides, the influence is too slight and obscure to justify a consideration of lunar and planetary effects in the actual work of weather forecasting.

3. That the stars have no appreciable influence upon the weather.

4. That animals, birds, and plants show by their condition the character of past weather, and by their actions the influence of present weather and the character of weather changes that may occur within a few hours.

5. That the weather of days, months, seasons, and years affords no indications of future weather further than showing present abnormal conditions that the future may adjust.

6. That six and seven day weather periods are too ill-defined and irregular to be applicable to the actual work of forecasting.

7. That advances in the period and accuracy of weather forecasts depend upon a more exact study and understanding of atmospheric pressure over great areas and a determination of the influences, probably solar, that are responsible for normal and abnormal distributions of atmospheric pressure over the earth's surface.

8. That meteorologists are not antagonistic to honest, well-directed efforts to solve the problem of long-range forecasting; that, on the contrary, they encourage all work in this field and condemn only those who, for notoriety or profit or through misdirected zeal and unwarranted assumptions, bring the science of meteorology into disrepute.

9. That meteorologists appreciate the importance to the world at large of advances in the period of forecasting and are inclined to believe that the twentieth century will mark the beginning of another period in meteorological science.







BULLETIN No. 36. W. B. No. 242.

Price, \$1.50.

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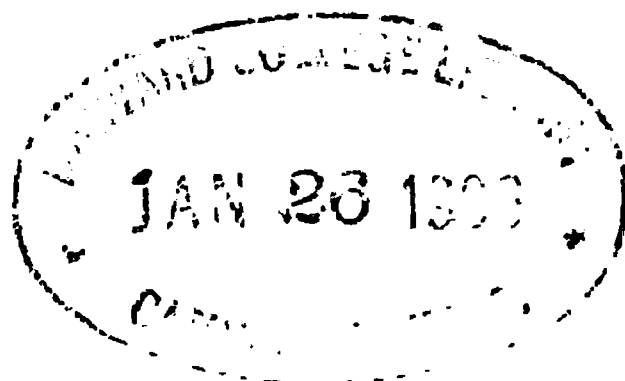
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*Chief United States Weather Bureau.*

WASHINGTON:  
GOVERNMENT PRINTING OFFICE,  
1905.

Sci 769.115



From the  
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## LETTER OF TRANSMITTAL.

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UNITED STATES DEPARTMENT OF AGRICULTURE,  
WEATHER BUREAU, OFFICE OF THE CHIEF,  
*Washington, D. C., August 1, 1905.*

HON. JAMES WILSON,  
*Secretary of Agriculture, Washington, D. C.*

SIR: I have the honor to submit the manuscript of a first report, by Prof. Cleveland Abbe, on the Relations Between Climates and Crops, and to recommend its publication as a bulletin of the Weather Bureau.

This paper is not designed as an original investigation, but as a summary of the views of the best experimentalists and observers, so far as those had been published up to 1891. A continuation of this study, bringing the subject up to date, is contemplated; but as the publication of this first portion has been frequently requested, it seems wise not to delay.

The author has intended to notice only those investigations that have given precise information as to specific plants or crops and specific localities, and has made a thorough search of all the more important literature, in so far as it was accessible to him; it is believed that the numerous extracts given by him will be gratefully received by those who have not access to the same volumes.

The work is prepared with the idea that it will be especially useful to the teachers of the agricultural colleges and the investigators of the agricultural experiment stations. Therefore only a limited edition is recommended.

As the memoir points out the importance of a climatic laboratory and the methods that must be pursued in order to evolve new varieties of crop plants adapted to special climatic conditions, I can but consider that you will recognize this memoir as a proper contribution to agriculture from the Weather Bureau.

Very respectfully,

WILLIS L. MOORE,  
*Chief U. S. Weather Bureau.*

Approved:

JAMES WILSON.

*Secretary.*



## PREFACE.

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Several experts in agricultural science having stated to me their need of a systematic summary of the present state of our knowledge with regard to the specific influence of climate in agriculture and its relation to or absolute effect on the percentages of the resulting harvest, and the subject being one in which I had long been interested, I therefore presented the matter to the Chief Signal Officer, who thereupon issued an instruction, dated February 25, 1891, authorizing me to prepare this work, completing it before June 30 of that year. The present report is a rapid compilation from a wide range of sources, and presents a preliminary view of the condition of our knowledge at that time as to the effect of climate upon the growth and distribution of our staple crops. As far as practicable I have presented, in the words of the respective authors, the results of their own investigations on the points at issue, my own duty being not to undertake any extensive original study, but to merely connect their results together in a logical manner, to collect data for future general use, and to suggest, or stimulate, further inquiry on the points here presented. I regret that the report could not have been published in 1891, as many of the ideas presented therein have by delay thus been withheld from their practical applications to the benefit of agriculture.

As the study of phenology and agriculture, in the modern spirit, has been cultivated for over a century in Europe, much of our knowledge must be drawn from European literature, which is really far too extensive to be satisfactorily summarized in the time and space at my disposal. Originally it was my hope to introduce into this report a summary of the large and sadly scattered literature of American phenology, including the dates of blossoming and ripening both of native and cultivated plants, enlarging the work already done in this line by F. B. Hough for the State of New York; but I did not succeed in completing this part of the work, and reserve it for a future occasion. Requests for phenological observations in the United States have been frequently made since 1800, and large collections of data exist in manuscript and print sufficiently extensive to justify the hope that they may prove worthy of a study as elaborate

as that which European observations have received at the hands of the lamented Linsser.

The very extensive problem suggested by the title of this report involves, first, a general study of meteorology in its relations to vegetable and animal life; second, the determination of the effect of climate upon the growth and distribution of staple crops; third, the determination of the climatic conditions and the localities best suited to the growth of special varieties of plants and seeds; fourth, the statistics of the extent of the areas best adapted to each of the more important crops; fifth, the separate and the combined effects of temperature, rainfall, and sunshine, both in their normal and abnormal proportions, upon the annual yields of the staple crops. But such study necessitates great labor and much time, and as the first step in any such investigation consists in the critical examination of the work already done by others, in order to prevent unnecessary duplication and avoid the troubles that others have experienced, therefore the reader must consider this first report as only a brief introduction to our knowledge of the relations between climates and crops.

Three ways are generally recognized as affording our only methods of advancing our knowledge of our subject, viz, physiological, experimental, and statistical. I shall therefore endeavor to present the question of climates and crops from these three points of view.

1. The physiological studies of many botanical physiologists, under the leadership of Prof. Julius von Sachs, of the Botanical Institute at Würzburg, Germany, have given us an insight into the method of growth of plants and the conditions upon which successful agriculture must depend. Their conclusions, based upon microscopic examination, delicate measurements, and detailed study of all the minutiae in the life of a plant, have given occasion to the development of what may be called a theory of vegetable life, which, however, is still far from having reached a perfect stage of development. Under this head I have collected observations relative to the germination of seeds, the flow of the sap, the action of sunlight on the leaves, the absorption of moisture by the roots, the transpiration from the leaves, the ripening of the seeds, the nutritious value of the crop, and the acclimatization of plants.

2. The experimental method of determining the relations of crops and climates is that practiced at agricultural experiment stations and also in the botanical or biological laboratories that are so plentiful in the United States and in Europe. In these institutions special seeds are sown with special care, either in the open air in small plats of ground or in culture pots in rooms where the temperature, moisture, and other conditions are under control. The numerous abstracts that I have presented in this report tend to show the effect of varying conditions upon the resulting crops, and I must agree heartily

with De Candolle in his plea for a climatic laboratory. It is evident that in such an institution one may reproduce to perfection the climatic conditions under which a given seed was grown, and thus insure a maximum crop; or, on the other hand, by successive cultivations, under successive slight changes in the artificial climate, may so modify the seed as to produce a new variety with a fixed habit of growth adapted to any natural climate that the farmer has to deal with. The laws of acclimatization that naturally follow from Linsler's investigations, and, in fact, from general experience in all parts of the world, point to this as a most important field of future usefulness. It is thus that we may hope to accelerate the natural course, which, on the one hand, has already produced grains adapted to the Russian steppes, and, on the other, will eventually evolve those adapted to the vicissitudes of our own arid regions and possibly our severe Alaskan climate.

3. The statistical method of ascertaining the effect of a climate on the resulting crop consists in comparing the statistics of the successive annual harvests in the country at large with the statistics of the prevailing climatic conditions. At the close of this report I have given a large collection of data of this kind, sufficient, I think, to show that this method is very unsatisfactory because of our ignorance of the many details that must be considered in discussing the statistical figures. I have compiled these elaborate tables for the United States from the data given by the former Statistician of the Department of Agriculture, Mr. J. R. Dodge, and his able assistant, Mr. Snow, and have indicated a method of treating these figures which will, I think, eventually give us the best results that they are capable of affording, and will be, perhaps, sufficiently accurate for the needs of the farmer, the merchant, and the statesman, but which can scarcely respond to the exact demands of agricultural physics. The great collection of data given in the reports of the Tenth and Eleventh censuses of the United States for the crop years 1879 and 1889 will, I hope, tempt some one to an extended study for those years.

I shall not devote much space to the question of the relative influence of forests and cultivated fields on the temperature and moisture of the local air. This has become a special study on the part of those devoted to forestry, and the papers of Professor Ebermayer (1873), Muttrich (1880), Nordlinger (1885), and others<sup>a</sup> teem with figures to show that in the heart of an extensive forest the mean daily variations of temperature or the range from minimum to maximum is, on the average, from 2° to 5° C. less than in the open air just outside the forest, while a similar difference of only 1° to 2° C. exists for the

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<sup>a</sup> The full titles of the works referred to in this report will be found in section on "Bibliography," Part IV.



annual ranges of temperature. Some attempts have also been made to show that in a forest region more rain falls than in adjacent open fields; but this I shall not further consider, as I have elsewhere shown that the measured differences are all due to the influence of the wind on the catch of the rain gage and have nothing to do with rainfall itself. All reliable observations show that the percentage of moisture in the soil is larger under the forest than in the open air, and all investigations show that the temperature of the soil is far more uniform under the forest than in the full sunshine.

The proper conclusion to draw from these forest studies, in so far as they relate to the question of the influence of climate on crops, is simply that plants growing within the influence of a forest have a somewhat different climate from those growing in the open field. The amount of this influence will become a proper study when any important crop is cultivated within a forest or under its influence, which, however, is not now generally the case.

The inverse question as to the influence upon general atmospheric phenomena of the temperature and moisture of the thin layer of quiet air within a region covered with a forest is one that may be relegated to the future as being of minor importance in dynamic meteorology and of still less importance in agricultural climatology.

On the other hand, the distribution and quality of forest trees affords a very important illustration of climatic influence. Indeed, the forests themselves furnish a most important crop of lumber and firewood, perhaps the most valuable crop recorded in the statistics of the country, and one whose relation to climate must be important, but, unfortunately, the statistics of annual forest growth are not yet available for this study. I have, therefore, deferred the consideration of this branch of our subject to a future date, when perhaps American forestry will be more fully developed.

I shall omit the consideration of theories and experiments as to the artificial improvement of the weather, especially the production of rainfall, protection from hail and lightning, and the amelioration of our hot winds. Although this subject is alluring, I hope the common sense of the agricultural community will eventually indorse my conviction that, for the present, our wisest plan is to confine our study closely to, first, the influence of sunshine, heat, moisture, and atmosphere on the growth of plants, on the nature of the seed, and on the character of the crops; second, the influence of the quality of the seed itself and of the richness of the soil on the crop; third, how to choose our seed, cultivate the ground, and protect the plant from frost, birds, insects, fungi, etc., so as to secure a good crop in spite of adverse natural climatic conditions.

In general, I have labored to put my data and conclusions before the reader so fully that, if a student, he may utilize this report as a

basis for further generalizations, or, if a farmer, he may derive many suggestions, hints, and rules by which to improve his methods.

Very few appreciate the extensive range of edible plants, but the lists given by E. L. Sturtevant (*Agr. Sci.*, Vol. III., p. 174) suggest that we have in the botanical world an almost unexplored field from which to recover for the use of civilized man an endless variety of foods and fruits unknown to our present cuisine and table. Sturtevant enumerates in detail the 210 natural orders of plants recognized by botanists from the days of Linnæus to those of Bentham and Hooker. These orders include 8,349 genera and 110,663 species, and Sturtevant shows that the edible plants include only 4,233 species, representing 170 of these orders, so that only about  $3\frac{1}{2}$  per cent of the known species of plants are now being used as food—most of them, of course, to a very slight extent, only as auxiliaries to the principal foods.

The food plants extensively cultivated by man include only 1,070 species; that is to say, less than 1 per cent of all known species are cultivated anywhere throughout the known world, and those actually in ordinary use in European and American kitchen gardens represent only 211 species. The preceding numbers all refer to the phenogams, but Sturtevant gives supplementary lists covering the lower order of plants.

Therefore it would seem that the present condition of agriculture and the present extent of our available vegetable foods is limited not so much by our climate and soil as by our ignorance of the laws of nature affecting plant life. We may not control the climate, but we may rear natural plants and adopt rational methods of modifying them by cultivation until they and we become quite independent of the vicissitudes of drought and frost.

In conclusion I gratefully acknowledge the enthusiastic assistance that I have received from Mrs. R. S. Hotze as translator, and Mr. E. R. Miller in the preparation of the index.



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# A FIRST REPORT ON THE RELATIONS BETWEEN CLIMATES AND CROPS.

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## PART I.—LABORATORY WORK, PHYSIOLOGICAL AND EXPERI- MENTAL.

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### Chapter I.

#### GENERAL REMARKS.

It is not possible to conceive of an intelligent solution of the complex problems offered by plant life in the open air and cultivated fields without first considering the innumerable experiments that have been made by experimental botanists. It is therefore necessary for the student and the practical man alike to know something of the laws of growth, as presented in the elaborate treatises by Sachs, Vines, Goodale, and others. I will at present simply collate those special results that bear upon crops as the final object of agriculture and confine myself very closely to the relation between the crop and the climate, in order to avoid being drawn into the discussion of innumerable interesting matters which, although they may affect the crop, yet are understood to be outside the province of climatology. By this latter term I understand essentially the influence on the plant of its inclosure, i. e., the sky or sunshine, soil, temperature, rainfall, and the chemical constitution of the air, either directly or through the soil.

#### THE VITAL PRINCIPLE—CELLULAR AND CHEMICAL STRUCTURE.

The growth of a plant and the ripening of the fruit is accomplished by a series of molecular changes, in which the atmosphere, the water, and the soil, but especially the sun, play important parts. In this process a vital principle is figuratively said to exist within the seed or plant and to guide the action of the energy from the sun, coercing the atoms of the soil, the water, and the air into such new chemical combinations as will build up the leaf, the woody fiber, the starch, the pollen, the flower, the fruit and the seed.



A climate that is favorable to a special crop is one whose vicissitudes of heat and rain and sunshine are not so extreme but that they can easily be utilized by the sunbeams in building up the plant. An unfavorable climate is one whose average conditions or whose extreme vicissitudes are such that the vitality of the plant—namely, its power to grow—can not make headway against them. In extreme cases, such as frosts, sudden thaws, and great droughts, the climate may even destroy the organic material that had already been formed in the plant.

No plant life, not even the lowest vegetable organism, is perfected except through the influence of the radiation from the sun. It may need the most intense sunlight of the Tropics, or it may need only the diffuse and faint light within dark forests or caves. Heat alone may possibly suffice for the roots and certain stages of growth, but a greater or less degree of light—i. e., energy delivered in short-wave length or rapid periodic oscillations—is necessary for the eventual maturity. The radiation from any artificial light, especially the most powerful electric light, will accomplish results similar to that of sunlight; therefore, it is not necessary to think that life or the vital principle is peculiar to or emanates from the sun, but on the contrary that living cells utilize the radiations or molecular vibrations so far as possible to build up the plant.

We know nothing about the nature of this vital principle, but we can, by the microscope, demonstrate that the essential ultimate structure of the plant or seed is a minute cell, namely, a very thin skin or film or membrane inclosing a minute portion of matter consisting of mixed liquids and solids. This skin is called the wall of the cell; in the early growth of the cell its inclosed liquid is called the protoplasm. By crushing many such young cells we may obtain enough of either part to make a chemical examination and find that the cell wall is a complex chemical substance called cellulose, composed of carbon, hydrogen, and oxygen. By molecules this compound is  $C_{18}H_{30}O_{16}$ ; by weight cellulose has C 44.44, H 6.17, O 49.39 per cent. As the cells become older their walls become thicker and are incrustated internally with additional matters, such as gums, resins, etc., until the cell wall refuses to perform its original functions. Such old cells are not easily digested by man or animals and are not considered as food or reckoned among the food crops, but young cells in succulent stems, leaves, and fruits, or the crushed cells of seeds and grains, are nutritious food. Flax, cotton, jute, straw, wood pulp, and many other mature dried cells form the important crops of textile fibers.

The protoplasm within the cell is generally an albuminous com-

pound or albuminoid, viz, besides having carbon, hydrogen, and oxygen, it also contains considerable nitrogen and a little sulphur or phosphorus or iron or other substances, thus forming albumen, whose chemical constitution is expressed by the approximate molecular formula  $C_{72}H_{110}N_{18}O_{22}S_1$ , or by weight C 53, H 7, N 16, O 22, S 1 per cent. Possibly this molecular formula is more properly written  $3(C_{24}H_{38}N_6O_8)$ , plus the addition of sulphur compounds such as to make the whole become as before written. Mulder supposed that a certain substance which he called *proteine*, and whose composition is supposed to be  $C_{36}H_{26}N_6O_{10}$ , is the basal molecule of albumen; two such molecules, with additional quantities of nitrogen, hydrogen, and oxygen, combined with a little sulphur, phosphorus, iron, or other mineral, make up, according to him, the constitution of the ordinary albuminoid. But his views are not considered altogether acceptable.

The constituent chemical elements contained in cellulose are precisely the same as those of starch, whose formula is  $C_6H_{10}O_5$ , but the arrangement of the atoms and molecules among themselves is undoubtedly very different, so that the physical and chemical properties of starch and cellulose are very different. Starch, diastase, and cellulose may be considered as substances composed of molecules whose internal structures are respectively more and more complex; in the molecules of each of these substances the carbon, hydrogen, and oxygen are in the same proportions relative to each other both by number and by weight, but a molecule of diastase has twice and one of cellulose three times as many atoms as a molecule of starch. The composition of pure water is represented by the molecular formula  $H_2O_1$ , or by weight H 11, O 89, so that starch may be considered as a compound of 6 atoms of carbon with 5 molecules of water. From the same point of view diastase would be compounded of 12 atoms of carbon and 10 molecules of water, while cellulose would consist of 18 atoms of carbon and 15 molecules of water. These three substances are therefore called *carbohydrates*, as though carbon combined with water were to be considered as carbon combined with hydric acid. This term is not to be confounded with the word "hydrocarbon," which is applied to any compound of hydrogen and carbon, which, when combined with water or other molecules, forms a very different series of chemicals, such, for example, as  $C_4H_6$ , which is a hydrocarbon and when combined with 4 molecules of water or hydric oxide forms alcohol, making the latter, as it were, a hydrate of a hydrocarbon.

The approximate percentages by weight of the cellulose found in plants and vegetables dried at a temperature of 212° F. and the per-

centage of albuminous compounds for air-dried crops are given as follows:

Plant.	Cellulose (dried at 212°).	Albumi- noids (air dried).	Plant.	Cellulose (dried at 212°).	Albumi- noids (air dried).
Potato tubers.....	1.1	-----	Beans.....	-----	24-41
Wheat kernels.....	8.0	11-20	Red clover hay.....	84.0	12-20
Maize kernels.....	5.5	10-16	Timothy .....	23.0	-----
Barley kernels.....	8.0	12-16	Oat straw .....	40.0	-----
Oat kernels .....	10.8	11-17	Wheat straw.....	48.0	3- 4
Buckwheat kernels.....	15.0	10-14	Rye straw.....	54.0	8- 4
Peas.....	-----	22-36			

This crude chemical analysis of the walls and of the contents of the crushed cells tells us nothing of the life that had previously resided in the uncrushed organisms, but prepares us for the statement that the development of a plant implies a great amount of work done among the molecules in rearranging them into the places where they are needed. These molecules come from the simpler atoms in the soil, the air, and the rain water, but the force and energy that does the work of building them up comes, so far as we know, from the sunshine. It is a case of the transformation of energy. Within the cells of a plant the molecular energy, or the so-called "radiant energy," that would otherwise produce the phenomena of heat and light is transformed into chemical activity and produces the new molecular compounds that we use as food. We and other animals can not produce these compounds in our own bodies, but we can utilize them if they are not injured in the process of cooking.

#### GENERAL RELATIONS OF THE SEED AND PLANT TO THE AIR AND THE SOIL.

##### RESPIRATION.

It is known that in the act of germination the seed absorbs oxygen from the air contained in the interstices of the soil and that very few seeds will germinate when the soil and the water are deprived of air or free oxygen.

As to the full-grown plant, it is commonly said to absorb carbonic-acid gas from the air through its leaves and to exhale oxygen. The investigations of Moisson tend to modify this statement and show that at low temperatures there is more oxygen absorbed than there is carbonic-acid gas produced, while at high temperatures the reverse is true. For each plant there is a certain temperature at which each volume of carbonic-acid gas absorbed is replaced by an equal volume of oxygen exhaled by the leaves. Thus in the case of the *Pinus pinaster* for every 100 volumes of oxygen absorbed there are 50 volumes of carbonic-acid gas exhaled at 0° C. temperature, but 77 volumes at 13° C. and 114 volumes at 40° C.

Evidently this whole process of respiration depends largely upon the temperature of the air and is more active as the temperature increases. It goes on both in darkness and in light, but with this difference—that in darkness more carbonic-acid gas is given out than the oxygen that is absorbed, whereas, on the other hand, under the influence of light more oxygen is given out than the carbonic-acid gas that is absorbed. Both these processes are stimulated by heat. The assimilation or nutrition of the plant depends upon this mechanical influence of light in disengaging oxygen and “fixing” the carbon of the gas in the cells of the plant. Plant respiration is accompanied by two distinct but correlated phenomena, which are defined by Marie-Davy (1882) as “evaporation” and “transpiration.”

*Evaporation.*—This is a purely physical phenomenon. All bodies lose water from their external surfaces when in contact with dry air, and do so faster in proportion as the wind is stronger and the air is drier. Evaporation takes place for dead and living surfaces alike.

*Transpiration.*—This is a physiological and not a purely physical phenomenon. It occurs only in living plants and under the influence of light; it is independent of the dryness of the air and is only indirectly dependent on temperature. It is intimately connected with assimilation, since by its means materials are furnished to complete the work of the growth of the plant.

#### DRYNESS, TEMPERATURE, AND VELOCITY OF THE WIND.

The evaporation from the leaves, the flow of sap, and the development of the plant depend almost as much on the wind and the dryness of the air as they do on the temperature of the air considered by itself, since all these are necessary in order to bring the supply of nutritious water up to the leaf. Therefore, the temperature of the air must not be considered as the only important climatic element controlling vegetation. At the time of the bursting of the buds in the spring, when no leaves are on the trees and when the respiration of the plant and the evaporation are at their minimum, the temperature and dryness of the air have their least influence, while the temperature and moisture of the soil may have their maximum relative importance. These latter are the elements that determine how much water shall be absorbed and pushed upward as sap. It is under the influence of this upward pressure of the sap that the sunlight manufactures the first buds and leaves. The temperature of the air flowing among the branches and buds may have any value without seriously affecting the development of the plant, provided it is above freezing and below a destructive temperature, such as 120° F., and above a destructive dryness, such as 5 or 10 per cent of relative humidity. Ordinarily a warm spring day implies a warm, moist soil and a warm,

moist atmosphere. Man naturally observes first the latter feature, which is so important to him, and then associates it with the budding of the plant, but he recognizes his mistake when he considers that the plant is firmly established in the earth and that its nourishment and growth must depend primarily on the condition of the soil and roots.

#### TEMPERATURE AND MOISTURE OF THE SOIL.

The temperature of the soil a short distance below the immediate surface does not depend, by way of cause and effect, primarily on the temperature of the air. It is not warmed or cooled appreciably by conduction of atmospheric heat, but by direct absorption or loss of the radiation that falls upon it. To a slight extent (perhaps 5 per cent) this sunshine is reflected from the surface particles of the ground according to the laws of simple reflection; the remainder is absorbed by the surface and warms it. This warmed surface layer immediately radiates back a small quantity (10 per cent) as long waves into the atmosphere and through that into space, since the atmosphere does not absorb these long waves, but it gives up a larger part, perhaps 50 per cent, by conduction to the adjacent lowest layer of air, which being thus warmed quickly rises and by convection distributes this 50 per cent of heat throughout the atmosphere, whence it is eventually radiated back into space. The remaining 40 per cent of the solar heat is by conduction carried downward through the solid earth; a large portion is consumed in the evaporation of soil water and returns to the atmosphere with the aqueous vapor; the rest goes on downward, warming up the soil until it arrives at a layer 30 to 50 feet below the earth's surface, where the gradient of temperature just in front of it is the same as that just behind it. Here the heat would accumulate and push its way still deeper were it not that by this time, in most cases, the diurnal and annual changes of temperature at the earth's surface, where this heat wave started, have brought about a deficiency just below the earth's surface; consequently the heat that had reached the depth of 30 or 50 feet now finds the temperature gradient just above it beginning to reverse, wherefore this heat begins to flow back, upward, and outward. In this manner the temperature of the ground increases downward to a depth of a few yards during certain months and then upward during other months, in diurnal and annual fluctuations interspersed with irregular changes, depending on cloud and wind and rain, all of which are easily recognized by examining any system of curves representing the earth temperatures at different depths throughout the year.

The ground is warmed by the air only in case the temperature of the surface soil is lower than that of the air, and, although this happens frequently, yet the quantity of heat thereby communicated

to the ground is comparatively slight, owing to the slow conductivity of the soil and the small specific heat of the atmosphere. This point has been carefully developed by Maurer, of Zurich (1885). But when rain and snow fall, then the latent heat formerly contained in the atmospheric vapor is quickly given to the surface soil and directly conducted deeper into the ground, and the latter is warmed or cooled according as the rain or snow is warmer or cooler than it. In general, the warming of the soil by warm rain is less important than the cooling by cold rains, melting snows, and evaporating winds.

#### CLOUDINESS.

When clouds intervene the soil receives a smaller proportion of direct solar heat, and the proportion diminishes as the thickness of the cloud layer increases or as the proportion of cloudy sky to clear sky increases. We may adopt the approximate rule that the warming effect of the sunshine is inversely as the cloudiness of the sky within  $45^\circ$  of the zenith; thus for a sky covered by 10 cumulus or 10 stratus the direct solar heat at the ground is 0; for 10 cirrus or cirro-cumulus or cirro-stratus the solar heat is about 5, while for 0 cloudiness the radiation that the observer receives is 10.

#### SOIL THERMOMETERS.

The motions of the clouds do not affect the sum total of the intensity of the sunshine, but the variations of cloudiness are so important that it is best to make use of some form of sunshine recorder or, better still, some form of integrating actinometer as a means of determining the relative effectiveness of the sunshine for any hour or day. If any such instrument shows that during any given hour, with the sun at a known altitude, the duration of the effectiveness of the sunshine was the  $n$ th part of the maximum value for clear sky, then we may assume that the heating effect of the sun on the surface of the soil was the  $n$ th part of its maximum value and may thus ascertain and, if need be, approximately compute the irregularities of the diurnal waves of heat that penetrate the soil. But these irregularities are directly shown by thermometers buried in the soil at different depths, and the observation of such soil thermometers is an essential item in the study of climate and vegetation. The absence of these observations has necessitated much labor in unsatisfactory efforts to obtain the approximate soil temperatures from the ordinary observations of air temperature, radiation thermometers, clouds and sunshine.

Fortunately the agricultural experiment stations of the United States have begun the observation of soil temperatures as distin-



guished from the deep-earth temperatures that have for a century past interested the student of terrestrial physics but do not affect agriculture. I shall hereafter give a synopsis of such records so far as they are available to me; but so much agricultural data has been collected, both in Europe and America, without corresponding soil temperatures that we also need the data and methods that may be used for estimating soil temperatures from ordinary meteorological observations.

#### SUNSHINE.

Climatology usually considers the temperature of the air as given by thermometers that are shaded from the effect of sunshine; this is the temperature of the air very nearly as given by the whirled or ventilated or sling thermometers and is that which is needed in dynamic meteorology. But the sunshine produces important chemical effects besides its thermal effects, and these have no simple relation to each other. It is therefore very important that we have some method of recording the duration, intensity, and quality of the total or general radiation that the plant receives from the sun and from the sun and the sky combined. Up to the early part of the nineteenth century the optical and thermal effects of sunshine were spoken of as due to certain imponderable forces called light and heat that were supposed to be combined in the complex solar rays, but which can be separated from each other. But we now believe it to be correct to speak of the sunshine as a complex influence, a radiation of energy, whose exact nature is problematical, but whose mechanical effects when it acts upon terrestrial matter we know, measure, and study as the phenomena of light, heat, electricity, gravitation, chemism, and vitality.

#### DISTRIBUTION OF CLIMATIC ELEMENTS RELATIVE TO THE LIFE OF THE PLANT.

As before stated, plants respire during both day and night. The pores of the leaves are always absorbing and emitting gases, but when the sun shines on the leaves, and more especially with the help of the yellow part of the solar spectrum, the chlorophyl in the leaf cells is able to decompose the carbonic acid absorbed by the plant, retaining carbon and rejecting the oxygen.

So long as the plant absorbs more carbon from the air and more nitrogen from the soil than it loses by any process it is continually increasing its leaf surface and the nutrition in its sap, laying up a store of nutriment for future use. This process ceases in the case of annual plants when the seed or grain or fruit begins to ripen; from this time forward the seed makes a steady draft upon the nutriment already stored up in the plant which goes to perfect the seed. In

this season of its growth the plant really needs less water than before, but still its roots have the same power of absorbing water, and if the sap is thus diluted there results a seed or fruit that is heavy with an excess of water. Of course this water will dry out, if it has an opportunity, after the harvest, but if it has no opportunity, on account of damp weather, it will remain in the seed and render the latter more subject to injury from fungi, whose spores are always floating in the air seeking a moist nidus or resting place favorable to their growth. Such moist seeds give a heavy, green harvest, but a light dried crop.

Thus it happens that the distribution of atmospheric heat, and moisture, as to time, is quite important in its effect on the local harvest.

Apparently the time of ripening of the harvest depends wholly upon the chronological distribution of water and sunshine, but the quantity and quality of the harvest, which are the important practical results to the farmer, depend upon the nutrition carried into the plant by the water that is absorbed by the roots.

#### IRRIGATION.

The determination of the right time for irrigation and of the proper quantity of water, in order to produce the best crop in soil of a given richness is the special problem of those planters who depend mostly upon irrigation for successful agriculture. In general it may be said that our ordinary seeds have long since been selected and acclimatized with a view to success in a climate where abundance of moisture is available at the proper season. Hence our crops are not so likely to be injured by excess of rain as by deficiency or drought. Therefore in almost every section, from the Rocky Mountains to the Atlantic, the highest success can only be attained by making provision for artificial irrigation in times of drought. The exact times and quantities of irrigating water depend upon the seed, the soil, and the evaporation, which latter is due to dryness of the air, the velocity of the wind, and the character of the soil; but when artificial watering or irrigation is needed to supplement natural rain one must seek to approximate as closely as practicable to the conditions presented in the countries where the seed originated, and especially the conditions presented during the seasons in which the given seed produced the best crops.

#### IMPORTANCE OF CLIMATIC LABORATORIES.

The studies that we are entering upon are greatly facilitated by experiments on a moderate scale under conditions that are under the control of the investigator, and free from the irregularities of open-air agriculture. The laws of nature can only be found out by questioning nature, as it were, by means of test experiments. Our present



needs in this respect are even more urgent now than they were thirty years ago, and I can not do better than to reprint and indorse the following appeal first made in an address by A. de Candolle in 1866:

It appears to me, however, that botanic gardens can be made still more useful in carrying out physiological researches. For instance, there is much yet to be learned on the mode of action of heat, light, and electricity upon vegetation. I pointed out many of these deficiencies in 1855 in my *Géographie Botanique Raisonnée*. Ten years later Prof. Julius Sachs, in his recently published and valuable work on *Physiological Botany*, remarks much the same deficiencies, notwithstanding that some progress has been made in these matters. The evil consists in this, that when it is desired to observe the action of temperature, either fixed or varied, mean or extreme, or the effect of light, it is exceedingly difficult, and sometimes impossible (when observations are made in the usual manner), to eliminate the effects of the constant variations of heat and light. In the laboratory it is possible to operate under more exactly defined conditions, but they are rarely sufficiently persistent; and the observer is led into error by growing plants in too contracted a space, either in tubes or bell glasses. This last objection is apparent when it is wished to ascertain the influence of the gases diffused in the atmosphere around plants, or that of the plants themselves upon the atmosphere.

Place plants under a receiver, and they are no longer in a natural condition; leave them in the open air, and the winds and currents, produced at each moment of the day by the temperature, disperse the gaseous bodies in the atmosphere. Everyone is aware of the numerous discussions concerning the more or less pernicious influence of the gases given off by from certain manufactories. The ruin now of a manufacturer, now of a horticulturist, may result from the declaration of an expert; hence, it is incumbent on scientific men not to pronounce on these delicate questions without substantial proof.

With a view to these researches, of which I merely point out the general nature, but which are immensely varied in details, I lately put this question: "Could not experimental greenhouses be built, in which the temperature might be regulated for a prolonged time, and be either fixed, constant, or variable, according to the wish of the observer?" My question passed unnoticed in a voluminous work where, in truth, it was but an accessory. I renew it now in the presence of an assembly admirably qualified to solve it. I should like, were it possible, to have a greenhouse placed in some large horticultural establishment or botanic garden, under the direction of some ingenious and accurate physiologist and adapted to experiments on vegetable physiology; and this is, within a little, my idea of such a construction:

The building should be sheltered from all external variations of temperature, to effect which I imagine it should be in a great measure below the level of the ground. I would have it built of thick brickwork, in the form of a vault. The upper convexity, which would rise above the ground, should have two openings—one exposed to the south, the other to the north—in order to receive the direct rays of the sun, or diffused light. These apertures should each be closed by two very transparent glass windows, hermetically fixed. Besides which, there should be on the outside means of excluding the light,

in order to obtain complete darkness, and to diminish the influence of the variations of temperature when light is not required. By sinking it in the ground, by the thickness of its walls, and by the covering of its exterior surfaces with straw, mats, etc., the same fixed degree of temperature could be obtained as in a cellar. The vaulted building should have an underground communication with a chamber containing the heating and the electrical apparatus. The entrance into the experimental hothouse should be through a passage closed by a series of successive doors. The temperature should be regulated by metallic conductors, heated or cooled at a distance. Engineers have already devised means by which the temperature of a room, acting on a valve, regulates the entry or exit of a certain amount of air, so that the heat regulates itself. Use could be made of such an apparatus when necessary.

Obviously, with a hothouse thus constructed, the growth of plants could be followed from their germination to the ripening of their seeds, under the influence of a temperature and an amount of light perfectly definite in intensity. It could then be ascertained how heat acts during the successive phases from sowing to germination, from germination to flowering, and from this on to the ripening of the seed. For different species various curves could be constructed to express the action of heat on each function, and of which there are already some in illustration of the most simple phenomena, such as germination, the growth of stems, and the course of the sap in the interior of certain cells. We should then be able to fix a great number of those minima and maxima of temperature which limit physiological phenomena. Indeed, a question more complicated might be investigated, toward the solution of which science has already made some advances, namely, that of the action of variable temperatures; and it might be determined if, as appears to be the case, these temperatures are sometimes beneficial, at other times injurious, according to the species, the function investigated, and the range of temperature. The action of light on vegetation has given rise to the most ingenious experiments. Unfortunately these experiments have sometimes ended in contradictory and uncertain results. The best ascertained facts are the importance of sunlight for green coloring, the decomposition of carbonic-acid gas by the foliage, and certain phenomena relating to the direction or position of stems and leaves. There remains much yet to learn upon the effect of diffused light, the combination of time and light, and the relative importance of light and heat. Does a prolonged light of several days or weeks, such as occurs in the polar regions, produce in exhalation of oxygen, and in the fixing of green matter, as much effect as the light distributed during twelve-hour periods, as at the equator? No one knows. In this case, as for temperature, curves should be constructed, showing the increasing or diminishing action of light on the performance of each function; and as the electric light resembles that of the sun, we could in our experimental hothouse submit vegetation to a continued light.

A building such as I propose would allow of light being passed through colored glasses or colored solutions, and so prove the effect of the different visible or invisible rays which enter into the composition of sunlight. For the sake of exactness nothing is superior to the decomposition of the luminous rays by a prism, and the fixing the

rays by means of the heliostat. Nevertheless, a judicious selection of coloring matters and a logical method of performing our experiments will lead to good results. I will give as proof that the recent most careful experiments concerning the action of various rays upon the production of oxygen by leaves and upon the production of the green coloring matter have only confirmed the discoveries made in 1836, without either prism or heliostat, by Professor Daubeny, from which it appears that the most luminous rays have the most power, next to them the hottest rays, and lastly those called chemical.

Doctor Gardner in 1843, Mr. Draper immediately after, and Dr. C. M. Guillemin in 1857, corroborated by means of the prism and the heliostat the discovery of Doctor Daubeny, which negatived the opinions prevalent since the time of Senebier and Tessier, and which were the results of erroneous experiments. It was difficult to believe that the most refrangible rays, violet, for instance, which act the most on metallic bodies, as in photometrical operations, should be precisely those which have least effect in decomposing the carbonic-acid gas in plants and have the least effect over the green matter in leaves. Notwithstanding the confirmation of all the experiments made by Doctor Daubeny, when repeated by numerous physicists and by more accurate methods, the old opinions, appearing more probable, still influenced many minds till Prof. Julius Sachs, in a series of very important experiments, again affirmed the truth. It is really the yellow and orange rays that have the most power, and the blue and violet rays the least, in the phenomena of vegetable chemistry, contrary to that which occurs in mineral chemistry, at least in the case of chlorid of silver. The least refrangible rays, such as orange and yellow, have also the twofold and contrary property, such as pertains also to white light, and which produces the green coloring matter of leaves or bleaches them according to its intensity. It is these, also, which change the coloring matter of flowers when it has been dissolved in water or alcohol. Those rays called chemical, such as violet and the invisible rays beyond violet, according to recent experiments confirmatory of those of ancient authors—those of Sebastian Pogglioli in 1817 and those of C. M. Guillemin—have but one single well-ascertained effect, that of favoring the bending of the stem toward the quarter from which they come more decidedly than do other rays; yet that is an effect perhaps more negative than positive if the flexure proceeds, as many still believe, from what is going on on the side least exposed to the light.

The effect upon vegetation of the nonvisible calorific rays at the other extremity of the spectrum has been but little studied. According to the experiments we have on this subject, they would appear to have but little power over any of the functions; but it would be worth while to investigate further the calorific regions of the spectrum by employing Doctor Tyndall's process—that is, by means of iodine dissolved in bisulphide of carbon—which permits no trace of visible light to pass.

How interesting it would be to make all these laboratory experiments on a large scale! Instead of looking into small cases or into a small apparatus held in the hand and in which the plants can not well be seen, the observer would himself be inside the apparatus and could arrange the plants as desired. He might observe several species at the same time—plants of all habits, climbing plants, sensi-

tive plants, those with colored foliage, as well as ordinary plants. The experiment might be prolonged as long as desirable, and probably unlooked-for results would occur as to the form or color of the organs, particularly of the leaves.

Permit me to recall on this subject an experiment made in 1853 by Professor von Martins. It will interest horticulturists, now that plants with colored foliage become more and more fashionable. Professor von Martins placed some plants of *Amaranthus tricolor* for two months under glasses of various colors. Under the yellow glass the varied tints of the leaves were all preserved. The red glass rather impeded the development of the leaves and produced at the base of the limb yellow instead of green; in the middle of the upper surface, yellow instead of reddish brown, and below, a red spot instead of purplish red. With the blue glasses, which allowed some green and yellow to pass, that which was red or yellow in the leaf had spread, so that there only remained a green border or edge. Under the nearly pure violet glasses the foliage became almost uniformly green. Thus, by means of colored glasses, provided they are not yellow, horticulturists may hope to obtain at least temporary effects as to the coloring of variegated foliage.

The action of electricity on foliage is so doubtful, so difficult to experiment upon, that I dare hardly mention it; but it can easily be understood how a building constructed as proposed might facilitate experiments on this subject. Respecting the action of plants on the surrounding air and the influence of a certain composition of the atmosphere upon vegetation, there would be by these means a large field open for experiments. Nothing would be easier than to create in the experimental hothouse an atmosphere charged with noxious gas and to ascertain the exact degree of its action by day and by night. An atmosphere of carbonic-acid gas might also be created, such as is supposed to have existed in the coal period. Then it would be seen to what extent our present vegetation would take an excess of carbon from the air, and if its general existence was inconvenienced by it. Then it might be ascertained what tribes of plants could bear this condition and what other families could not have existed, supposing that the air had formerly had a very strong proportion of carbonic-acid gas.

In hopes of realizing this idea of a complete botanic laboratory, the author spent his vacation of 1893 in the botanic gardens and greenhouses of Harvard University. On his return to Washington Professor Riley kindly offered him every convenience and space in the insectary of the Department of Agriculture. His 300 experimental plants of wheat and maize were, therefore, brought hither from Cambridge, Mass. But unforeseen difficulties arose, and it is to be hoped that the idea of an experimental laboratory for botanic study may be carried out by abler hands.

## Chapter II.

### GERMINATION.

#### INFLUENCE OF UNIFORM TEMPERATURE ON GERMINATION OF SEED.

The results of his own experiments on the germination of seeds at different temperatures were published by De Candolle (1865). His object was to determine the effect of long exposures at low temperatures as compared with short exposures at high temperatures. He eliminated various sources of complication and extended the observations made by Burckhardt (1858). Great pains were taken to keep the seeds at a uniform temperature; the water with which they were wetted was previously brought to the temperature required by the experiment. The first wetting was quite copious. The seeds were first covered with a thin layer of sand and the wettings frequently washed them bare, but no difference was observable in the epoch of germination for naked and covered seeds, showing that the temperatures in the inclosures were very uniform. The thermometers were carefully reduced to a standard Centigrade and their readings are probably correct within a tenth of a degree. The moment of germination is a delicate point to fix and is somewhat arbitrary. The embryo changes within the seed before any change shows itself on the outside. De Candolle takes as the moment of germination that when, the spermoderm being broken, the radicle begins to issue forth. Burckhardt in his experiments took as the epoch of germination the moment when the cotyledons show themselves; but in De Candolle's opinion this is rather an epoch of vegetation than the epoch of germination. It would perhaps be well to consider this phenomenon when we compare the same species under different conditions; but it varies very much from one species to another, since certain plants remain for a long time recurved under the earth or with their cotyledons imprisoned in the remnants of the spermoderm.

The seeds experimented on were as follows:

Cruciferæ.....	<i>Lepidium sativum.</i>
Do.....	<i>Sinapis alba.</i>
Do.....	<i>Iberis amara.</i>
Polemoniaceæ.....	<i>Collomia coccinea.</i>
Linaceæ.....	<i>Linum usitatissimum.</i>
Cucurbitaceæ.....	<i>Melon (cantaloupe).</i>
Ranunculaceæ.....	<i>Nigella sativa.</i>
Pedaliaceæ.....	<i>Sesamum orientale.</i>
Leguminosæ.....	<i>Trifolium repens.</i>
Gramineæ.....	<i>Zea mays, var. precoce.</i>
Amarantaceæ.....	<i>Celosia cristata.</i>



The conclusions which De Candolle draws from his experiments are as follows:

(A) AT A CONSTANT TEMPERATURE OF  $0^{\circ}$  C.

From the 7th of March to the 11th of April—that is to say, in 35 days' exposure to this temperature—the following seeds did not germinate at all: *Collomia*, *Lepidium*, *Linum*, *Zea mays*, *Melon*, *Nigella*, *Sesamum*, *Trifolium*, *Celosia*.

The only species which did germinate was *Sinapis*, the various seeds of which germinated in from 11 to 17 days, the latter seemed to De Candolle to be the more proper value of the time.

(B) AT TEMPERATURES FROM  $1.4^{\circ}$  TO  $2.2^{\circ}$  C.

*Collomia* and *Celosia* did not germinate in 35 days; *Lepidium* and *Linum* germinated in 30 and 34 days, respectively, under average temperature of  $1.8^{\circ}$ . *Zea mays* and *Nigella* did not germinate in 35 days; *Sesamum* did not germinate in 35 days; *Sinapis* germinated in 16 days, at an average temperature of  $1.9^{\circ}$ .

(C) AT TEMPERATURES VARYING BETWEEN  $2.6^{\circ}$  AND  $3.2^{\circ}$  C.

*Collomia* did not germinate in 36 days; *Lepidium*, about one-half of the seeds germinated, on the twelfth, sixteenth, and thirty-first days, respectively; *Linum* germinated on the seventeenth and eighteenth days, at an average temperature of  $3.1^{\circ}$ ; *Zea mays* did not germinate in 36 days; *Nigella* did not germinate; *Sesamum* did not germinate. Three *Sinapis* seeds germinated on the ninth, one more on the seventeenth day. A new sowing of *Sinapis* gave one seed germinating on the sixth day. Afterwards the temperature was allowed to rise gradually, but the seeds which had not germinated before came to nothing.

(D) AT TEMPERATURES FROM  $4.2^{\circ}$  TO  $6.1^{\circ}$  C.

About one-half the *Collomia* seeds germinated on the seventeenth day, at an average temperature of  $5.35^{\circ}$ ; *Lepidium* germinated abundantly on the eighteenth day; *Zea mays* did not germinate; about one-fifth of the *Linum* seeds germinated on the seventeenth day (average temperature  $4.8^{\circ}$ ); *Nigella*, *Sesamum*, and *Sinapis* did not germinate.

Possibly the moisture was too large in series (c) and (d).

(E) AT TEMPERATURES BETWEEN  $5.4^{\circ}$  AND  $6^{\circ}$  C.

Some *Collomia* seeds germinated in 14 days; *Lepidium* germinated freely on the fifth day; *Linum* germinated freely on the sixth day; *Zea mays* did not germinate in 36 days; *Nigella* germinated in twenty-seventh day; *Sesamum* did not germinate in 36 days; *Sinapis* germi-

nated abundantly the fourth day; *Iberis* germinated the fourteenth day; *Trifolium* germinated the tenth day; *Melon* did not germinate in 36 days.

(F) TEMPERATURES ABOUT 9.2° C.

*Collomia* germinated in 6½ days after sowing; *Lepidium* germinated the third day; *Linum*, 1 seed began to germinate the second day, several others the fourth; *Mays*, 1 seed germinated the tenth day, 2 others the twelfth day, and others afterwards; *Melon* did not germinate; *Nigella* germinated the fifteenth day; *Sesamum* did not germinate; *Sinapis* germinated at the end of 3½ days; *Iberis* germinated the sixth day; some *Trifolium* seeds germinated the fifth day, others the sixth, eighth, etc.

(G) TEMPERATURES FROM 12° TO 13° C.

For the first three days the average temperature of the soil was 12.9°. The individual results were as follows: *Collomia* germinated from the sixth to the seventh day; *Lepidium* germinated after about 1½ days (in a second experiment at 12.9° C. it germinated in 1½ days as before); *Linum* germinated in about 2½ days (in a second experiment at 13.5° it germinated at the end of 1½ days); 2 *Mays* seeds out of 17 germinated at the end of the fifth day, and half of them had germinated on the seventh day; *Melon* did not germinate during 60 days; a quarter of the *Nigella* seeds germinated the ninth day; *Sesamum* germinated abundantly at the close of the ninth day; *Sinapis* germinated after 1½ days (in a second experiment it germinated in about 40 hours, the average is 41 hours under a temperature of 12.9° C.); *Iberis* germinated in 3½ to 4 days; *Trifolium* seeds sprouted unequally at the end of the third day (a second experiment gave 3 hours less than 3 days, or 69 hours, under a temperature of 13°).

(H) TEMPERATURES OF ABOUT 17° C.

*Lepidium* (mean of two experiments) germinated in 1½ days, under 17.05°; *Linum*, mean of 2 experiments, germinated in 3 days, temperature 17.05° C.; *Trifolium*, 2 experiments, germinated in 2.6 days, temperature 17.05° C.; *Sinapas*, mean of 3 experiments, germinated in 1.7 days, temperature 17.2°; *Collomia*, 1 experiment, under 16.9° germinated in 5½ days; *Mays*, 1 experiment, germinated in 3½ days, temperature 16.9° C.; *Melon*, 1 experiment, began to germinate in 9½ days, temperature 16.9°; *Nigella*, 1 experiment, germinated the sixth day, temperature 16.9°; *Sesamum*, 1 experiment, germinated the third day, temperature 16.9°; *Iberis*, 1 experiment, germinated the fourth day, temperature 16.9°.

## (I) TEMPERATURES OF ABOUT 20° TO 21° C.

*Lepidium* germinated in 38 hours under 21.1°; *Linum* germinated in 36 hours under 21.1°; *Mays* began to germinate in 42 hours under 21.1°; *Nigella* germinated in 4½ days under 21.1°; *Sesamum* germinated in about 33 hours under 21.1°; *Sinapis* germinated in 22 hours on the average under 21.1°; some *Trifolium* seeds germinated in 42 hours under 21.1°; *Iberis* germinated in 2¾ days under 20.4°; only one *Collomia* seed germinated in 15½ days under 19.6°; 2 *Melon* seeds out of 10 germinated in 68 hours under 19.4°.

## (K) TEMPERATURES FROM 24° TO 25° C.

*Linum* germinated in 38 hours under 25.05°; *Mays*, 1 seed in 12 germinated in 23 hours (half the seeds had germinated within 44 hours under 25.05°); *Melon*, 2 seeds in 10 germinated in 44 hours, the others subsequently under 25.05°; *Sesamum* germinated in from 21 to 22½ hours under 25.05° (a second experiment gave 22½ hours under 24.6°); *Sinapis* germinated in about 36 hours under 25.05°; *Trifolium* germinated in 42 hours under 25.05°; *Nigella* and *Iberis* observations accidentally lost; *Lepidium*, 2 seeds in 10 germinated at the end of the sixth day, and the majority of the seeds between the sixth and seventh day under a mean temperature of 23.65°. A repetition gave 38 or 39 hours under a temperature of 21.1°; a third repetition gave 16 hours under a temperature of 26.5°, but which unfortunately ran up to 43° during a few hours. De Candolle concludes that there was some accident or mistake as to the first experiment, and therefore rejects it; probably the wrong seed was sown. He adopts for *Lepidium* 38 hours under 21.1° C. *Collomia* did not germinate until the twenty-seventh day, when 2 seeds sprouted under an average temperature of 21.5°.

## (L) TEMPERATURES OF ABOUT 28° C.

Two *Lepidium* seeds germinated in 39 hours, but the greater part not at all in 4 days; *Linum*, 1 seed germinated at the end of 2½ days, 3 seeds by the end of the third day, but the majority not at all; *Mays*, 1 seed germinated in 36 hours, and the majority, with vigor, in 48 hours; *Melon*, 1 seed germinated at the end of the third day, and the majority in 3¼ days; *Sesamum* germination began in 22 hours, and began to be abundant in 25 or 26 hours (a repetition gave 1 seed germinated in 31 hours under a temperature of 27.5° C.); *Sinapis*, 2 seeds out of 10 germinated at the end of the third day, a third seed 6 hours later, and the rest did not germinate; a few *Trifolium* seeds germinated at the end of the third day; *Collomia* and *Nigella* did not germinate in 8 days; a few *Trifolium* and *Linum* seeds germinated in 8 days under a temperature of 34°.



(M) TEMPERATURES FROM 40° TO 41° C.

Two *Sesamum* seeds germinated in 10½ hours under 40.7°, and the others immediately after; 3 *Melon* seeds germinated in 94 hours under 40.6°; none of the other seeds germinated at all in 4 days.

(N) HIGHER TEMPERATURES.

MM. Lefebure (1800) and Edwards and Colin (1834) have shown that most seeds undergo an alteration at a temperature of 50° C., so that they will not germinate after that, even when put under most favorable conditions. Some seeds when kept dry can be warmed in a stove almost to the point of combustion, but in water they lose the power of germination at 55° or 50°, or perhaps lower. In humid soil the seed is altered in proportion to the abundance of the water and the temperature of the soil. Thus, in De Candolle's above-given experiments, the seeds being kept quite wet could lose the power of germinating under 50° and perhaps under 34°, as some of the preceding experiments show, without, however, precisely defining this limit. Therefore De Candolle only experimented on the seeds of *Sesamum* at high temperatures with the following results: The temperature varied from 50° to 57° C. The seeds were watered copiously. One seed in 5 germinated in 25.7 hours at an average temperature of 51.5° C. On repeating the experiment, 3 seeds in 12 germinated at the end of 6 days, and 2 subsequently, but the majority did not germinate, the temperature having averaged 44° C. during the first 26 hours and 20° C. during the remainder.

For ease of study I have collected most of De Candolle's results for each of the eleven plants, respectively, into the following small tables:

Tables showing results of De Candolle's experiments on the germination of seeds at different temperatures.

LEPIDIUM SATIVUM.

Temper- ature.	Time.	Temper- ature.	Time.	Temper- ature.	Time.
°C.		°C.		°C.	
1.8	30 days.	9.2	8 days.	26.5	16 hours.
2.9	12 days.	12.9	1.75 days.	28.0	30 hours.
5.8	18 days.	17.05	1.5 days.		
5.7	5 days	21.1	88 hours.		

SINAPIS ALBA.

0.0	17 days.	9.2	8.5 days.	25.05	36 hours.
1.9	16 days.	12.9	41 hours.	28.0	72 and 78
2.9	9 days.	17.2	Do.		hours.
5.7	4 days.	21.1	22 hours.		

## IBERIS AMARA.

Temper- ature.	Time.	Temper- ature.	Time.	Temper- ature.	Time.
°C.		°C.		°C.	
5.7	14 days.	12.9	3.6 days.	20.4	2.75 days.
9.2	6 days.	16.9	4 days.		

## COLLOMIA COCCINEA.

5.35	17 days.	12.9	6.5 days.	21.5	27 days.
5.7	14 days.	16.9	5.5 days.		
9.2	6.75 days.	19.6	15.5 days.		

## LINUM USITATISSIMUM.

1.8	34 days.	9.2	2-4 days.	21.1	36 hours.
3.1	17 days.	12.9	2.75 days.	25.05	38 hours.
4.8	Do.	13.5	1.75 days.	28.0	2½-3 days.
5.7	6 days.	17.05	3 days.	34.0	8 days.

## MELON (CANTALOUPE).

16.9	9.25 days.	25.05	44 hours.	40.6	94 hours.
19.4	68 hours.	28.0	3.1 days.		

## NIGELLA SATIVA.

5.7	27 days.	12.9	9 days.	21.1	4.25 days.
9.2	15 days.	16.9	6 days.		

## SESAMUM ORIENTALE.

12.9	9 days.	25.05	21-22½ hrs.	27.5	31 hours.
16.9	3 days.	24.6	22½ hours.	40.7	10½ hours.
21.1	33 hours.	28.0	22-26 hours.	51.5	25.7 hours.

## TRIFOLIUM REPENS.

5.7	10 days.	13.0	69 hours.	25.05	42 hours.
9.2	5-6 days.	17.05	2.6 days.	28.0	72 hours.
12.9	72 hours.	21.1	42 hours.	34.0	8 days.

## ZEA MAYS.

9.2	10-12 days.	21.1	42 hours.	28.0	36 and 48 hours.
12.9	5-7 days.	25.05	23-44 hours.		
16.9	3.75 days.				

De Candolle's general conclusions are as follows:

(1) Contrary to the opinions of early investigators, such as De Seynes (1863) and Edwards and Colin (1834), it is now proven that some seeds, and probably others, do germinate in water at the temperature of 0° C.

(2) There is a minimum temperature at which each species germinates. These temperatures are as follows:

*Sinapis alba* germinates at 0° C., and possibly below this temperature if the water can be kept liquid.

*Lepidium* and *Linum* did not germinate at 0° C., but did germinate at 1.8° C.

*Collomia* did not germinate at 3° C., but did germinate at 5.3° C.

*Nigella*, *Iberis*, and *Trifolium repens* did not germinate at 5.3° C., but did germinate at 5.7° C.

*Mays* did not germinate at 5.7° C., but did germinate at 9° C.

*Sesamum* did not germinate at 9° C., but did germinate at 13° C.

*Melon* did not germinate at 13° C., but did germinate at 17° C.

Malvaceæ, *Gossypium herbaceum*; variety not specified: Some cotton seeds on which experiments had been made two years before would not then germinate, but did germinate at this time at 40° C.

*Raphanus sativus* (radish): Lefebure had shown that these seeds germinate at 5° or 6° C. as their minimum temperature.

*Triticum* (winter wheat), *Hordeum* (barley), *Secale cereale* (rye): All of these Gramineæ germinated at 7° C., according to Edwards and Colin, but this is probably not their minimum, for certainly barley will germinate at a lower temperature by prolonging the experiments.

We conclude, therefore, that each species has a minimum temperature at which it germinates, and the ordinary experience of the farmer would suggest this, but in his work one can hardly decide whether seeds sown too early in the springtime are simply retarded by specific low temperatures or whether germination is quite impossible. These present experiments show that if the temperature is too low, then germination is prevented. In calculations on the relation of temperature to vegetation one must consider only facts deduced from prolonged, constant temperatures. In the study of growth under natural conditions one must consider certain temperatures as useless and ineffective as concerns the germination of certain species of plants. There are, moreover, other facts that show that the same rule holds good for leafing, flowering, and maturing.

According to De Candolle's experiments, the species that require high temperatures as minima for germination are all from warm countries. Such species can not flourish in cold countries, for if they do germinate there this happens too late in the springtime and they can not ripen their fruits before winter. Among the species which germinate at low temperatures there are some that can exist in temperate climates, but these do not extend very far toward polar regions, either for reasons foreign to the germination or else because, having germinated too early, the delicate shoots are killed by frost.

(3) There is for each seed a maximum temperature beyond which germination is impossible. The above experiments determine such maxima approximately as follows:

*Nigella* does not germinate if the mean temperature exceeds 28° C.

*Collomia* does not germinate if the mean temperature exceeds 28° C.

*Trifolium repens*: Very few seeds germinate at 28° C., and probably none at 30° C.

*Mays*: Probably the upper limit is 35° C., although one seed germinated after being exposed to 50° C.

*Melon* will stand 40° C., but it is probable that above 42° C. germination is impossible.

*Sesamum* will stand 40° C., and possibly 45° C., the latter being the upper limit.

These upper limits, as I have before said, depend very much on the moisture, and on account of the difficulty of the experiment I have not endeavored to obtain great exactness.

*Lepidium* and *Linum*: According to the experiments of Burckhardt, some of these seeds have germinated after an immersion of half an hour in water at 50° C., but not after half an hour in water at 60° C.

*Raphanus sativus* (radish): Lefebure shows that these seeds germinate in moist earth at a maximum temperature of 38° C.

*Triticum* (winter wheat), *Triticum* (spring wheat), *Hordeum* (barley), *Secale cereale* (rye), and *Avena* (oats) germinate perfectly at 40° C., partially at 45° C., and not at all at 50° C.

(4) The range between the maximum and minimum temperatures at which germination is possible differs appreciably for these various species. Evidently a small range is a condition unfavorable to an extensive geographical distribution.

(5) Marked differences are observable between seeds of the same species and coming from the same place. This is well known to the farmer and strongly affected some of the preceding observations. The seeds of the same plant or the same capsule are not identical physically nor chemically. But if the temperature and moisture are those most favorable to germination, many seeds will sprout simultaneously, whereas near the maximum, and especially the minimum, temperature the seeds germinate very irregularly and many of them not at all.

(6) The structure of the seeds, especially the presence and nature of the albumen within them, ought to exert a definite influence, but the small number of species that De Candolle experimented upon does not allow of extensive generalizations.

The species having little or no albumen—viz, *Sinapis*, *Lepidium*, and *Linum*—germinate at very low temperatures. Those having the next larger amounts of albumen—viz, *Nigella*, *Collomia*, and *Zea mays*—germinate at about 5° C.; but *Sesamum*, which has but little albumen, requires 10° or 12° C.

At 17° or 18° C. all these seeds germinate well, but the length of time required increases somewhat as the albumen increases, showing that the latter exerts a retarding influence. The order of germina-

tion at this temperature is as follows: *Lepidium*, 1.5 days; *Sinapis*, 1.7 days; *Trifolium*, 2.6 days; *Sesamum*, 3 days; *Linum*, 3 days; *Iberis*, 4 days; *Zea mays*, 3.75 days; *Collomia*, 5.5 days; *Nigella*, 6 days; *Melon*, 9.25 days.

(7) The relation between temperature and the time required for germination is such that the time is shortest at a certain best temperature for each seed and increases to infinity or impossibility as we depart from that temperature toward the maximum and minimum limiting temperatures. All calculations of the sums of daily temperatures, both in geographical botany, in agriculture, and horticulture, are complicated by hypotheses and affected by many causes of inaccuracy, so that De Candolle hesitates to draw very precise conclusions from his laborious experiments. However, he shows that if the duration required for germination as expressed in days is multiplied by the corresponding temperature expressed in degrees Centigrade we shall then obtain much more consistent figures if the temperatures are counted from the minimum for each plant instead of from the zero of the Centigrade thermometer. The tables on pages 32 and 33 give the temperatures and the durations in days, as observed by De Candolle for the species experimented upon by him. For three of these he adopts as the starting point of his calculations the following minimum temperatures—viz, for *Lepidium*, 1° C.; for *Trifolium repens*, 5.5° C.; for *Sesamum*, 11° C.

(8) When seeds are subject to variable temperatures, as occurs to a slight degree in these experiments, and to a still larger degree in nature, the so-called useless or ineffective temperatures may be in fact unfavorable and even retard the germination, since moisture continues to be absorbed into the seed, although the latter can make no use of it.

(9) There is some analogy between the germination of seeds and the hatching of eggs. Thus Millet and Robinet have shown that the hatching of the eggs of the silk worm requires at least a temperature of 9° C., and that as the temperature increases above this the number of days required to hatch diminishes faster than required by a constant sum total, so that at a temperature of 20° C., ten days accomplishes more than twenty days will do at a temperature of 10°. This shows an influence of the minimum temperature similar to that for the seeds of plants.

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An entirely analogous case has been worked out by the author with regard to the hatching of the eggs of the grasshopper when deposited in the soil of our western plains. The details of this study will be found in the First and Second Reports of the United States Entomological Commission, and afford an illustration of the possibility of making from meteorological data a prediction as to the hatching

of the eggs of this pest, such as may guide the farmer in his sowing or planting so that the young plant may escape the ravages of the young insects.

### **INFLUENCE OF TEMPERATURE AND MOISTURE ON GERMINATION.**

The influence of temperature and moisture on the sprouting of seeds has been studied by Sturtevant at Cornell University (Agr. Exp. Sta., Bull. No. 7), with results generally confirming those of De Candolle. Sprouting occurs better with a uniform than with a variable temperature, so that the method of Quetelet, which requires us to take account of the squares of the temperatures, is no better than that which considers the simple temperature. The rapidity of sprouting diminishes with the decrease of temperature. The percentage of seeds that sprout does not depend upon the uniformity of the temperature. Sprouting takes place more rapidly in a rather dry soil, but a decidedly wet soil is injurious. By soaking the seed before planting it, the interval between planting and sprouting is diminished, but not between soaking and sprouting; hence the total time required and the total percentage of sprouting seeds is not much affected by the soaking. The exposure to light during germination retards some seeds, but does not affect others. Actual planting in the field may give 50 per cent less germinations than given by similar seeds planted in experimental pots under control.

### **INFLUENCE OF LIGHT AND HEAT ON GERMINATION.**

Pauchon (1880) summarizes the results of the studies of many authors on the relative influence of light and heat on the germination of seeds and the growth of plants. The following section is condensed from him:

Edwards and Colin (1834) state that in their day little was known as to the influence of light and air on the green matter and on the respiration of plants; since then, however, it may be considered as established that the life of a plant varies in proportion to the adaptation of the plant to its surroundings. The study of the influence of light may be said to have begun with Lavoisier, who thought that the light directly combined with certain parts of the plant producing the green leaves and colored flowers, and that without light there could be no life. Similarly Moleschott (1856), at Zurich, affirms that in general everything that breathes or moves draws its life from the light of the sun.

Boussingault (1876), controverting a statement of Pasteur, maintains that the growth of mushrooms and mold in the dark is not an exception but a confirmation of the general rule, and that if the solar

light should be cut off both the plants having chlorophyl, and also the plants that do not have it, would disappear from the surface of the globe.

Berthelot, in his essay on the mechanics of chemistry as based on thermochemistry, shows that the action of the light is demonstrated by the formation of complex chemical effects, isomeric changes, and more complex reactions. For instance, the combination of free oxygen is stimulated in a great many cases by the action of light, as is shown by the bleaching of fabrics of any kind exposed to the air and by the oxidation of volatile oils. All the oxidizing in reactions brought about by the action of light is exothermic—that is to say, there is a loss of energy in the transition from the compound body to its elementary components and a disengagement of heat. The light plays the rôle of a determining agent. On the other hand, when a complex body is built up in the cells of a plant, by drawing in elementary bodies from the atmosphere and soil, the reaction is endothermic, and solar heat is absorbed and rendered latent in the plant.

Sachs, Wiesner, and Mikosh would seem to have established the principle that the formation of the green matter of a plant is not dependent wholly on the light as such, but also demands a certain temperature, varying between  $0^{\circ}$  and  $35^{\circ}$  C., for the various plants of Europe. They show also that an increase in the temperature of the atmosphere, with equal increase of light, increases the rapidity of the formation of the chlorophyl up to a certain maximum temperature, and that in proportion as the temperature departs from this favorable maximum, either above or below, the formation of the green matter becomes less and less active, until when the limits  $0^{\circ}$  or  $35^{\circ}$  C. are exceeded it ceases altogether. But the temperature most favorable for the formation of chlorophyl under the action of light has but little connection with the temperature that promotes the further action of the chlorophyl after it has been formed within the plant. Thus Timiriazeff (1880) shows that the activity of the chlorophyl consists in the absorption of certain radiations; but in order that these radiations may act it does not suffice merely that they should be absorbed; it is further necessary that there should be a very considerable intensity of heat, in order to furnish to the chlorophyl the definite number of calories necessary for the decomposition of the carbonic-acid gas taken in from the atmosphere.

In general, under ordinary conditions light is indispensable to the formation of chlorophyl. To this general law there are a few apparent exceptions, as follows: The embryos of the genera *Pinus* and *Thuja* have their cotyledons colored an intense green at the moment of germination, even when they have been or appear to have been completely deprived of the action of light. So also with a certain number of phanerogams in which the embryo is protected by thick



integuments; finally, the fronds of certain ferns have a green color, even when they grow in complete darkness. With regard to the seeds of *Acer*, *Astragalus*, *Celtis*, and *Raphanus*, it has been shown by J. Böhm that when they germinate in darkness they do not acquire any green color; Flahault (1879) has obtained the same result for the seeds of the *Viola tricolor*, the *Acer pseudoplatanus*, and the *Geranium lucidum*. Similarly as to the other seeds above enumerated the studies of Sachs and Flahault render it probable that in most cases there was stored up in the seed certain reserve nutrition, which reserve, originally formed under the action of light, can subsequently in the act of germination temporarily replace the further direct action of light. It would thus seem that in no case can dark heat truly replace the action of sunlight.

On the other hand, light can replace heat in the process of vegetation. This was first shown by De Candolle, and a striking illustration is quoted by Moleschott (1856), who shows that by the influence of light during the resplendent nights of the polar regions the harvests ripen in a short time, while many days of our autumn heats in lower latitudes scarcely suffice. It is the quantity of light and the quality of the radiations that these plants receive that enable certain cereals, such as barley and oats, to be cultivated as far north as  $70^{\circ}$  of latitude. The observations of Schleiden on the potato, of De Candolle on the radiola, and of Haberlandt (1866) on oats, show that there exist decided differences in the quantities of heat necessary to the development of different species of vegetables under different latitudes, and that the most important cause of these differences is the quantity of light which these plants receive. De Candolle, in his botanical geography, says the effect of light is shown in the northern limits of certain species; thus the radiola is perfected by a total supply of heat represented by 2,225 day-degrees in the Orkneys at  $59^{\circ}$  north, but by a total of 1,990 day-degrees at Drontheim, latitude north  $63^{\circ} 25'$ ; the difference (235) corresponds to the fact that the longest day is  $1\frac{1}{2}$  hours longer at Drontheim than in the Orkneys, which increased sunlight enables the plant to complete its growth better under the same temperature.

Wheat furnishes a still more striking example. It begins to vegetate when the temperature in the shade is about  $6^{\circ}$  C., and observation has shown that it requires the following day-degrees to ripen: At Paris in 138 days, total shade temperature  $1,970^{\circ}$  C.; at Orange, 117 days, total shade temperature  $1,601^{\circ}$  C.; at Upsala, 122 days, total shade temperature  $1,546^{\circ}$  C.; at Lynden (North Cape), 72 days, total shade temperature  $675^{\circ}$  C. Or, if we use, not the shade temperatures, but those of a thermometer exposed to the full sunshine, as is done by Gasparin, then the above figures become at Orange, 2,468 day-degrees; Paris, 2,433 day-degrees; Lynden, 1,582 day-degrees.



These remarks of De Candolle with reference to germination are equally applicable to the whole period of growth of the plant.

As to the method of calculating the sum total of temperatures De Candolle found that it may be conducted in two ways, either by adding together all the mean daily temperatures above  $0^{\circ}$  C. or by omitting the useless degrees and adding all the others. This last method would seem to be the most logical, but can rarely be employed, owing to our ignorance of that minimum temperature below which all must be omitted. On the other hand, if we consider that a plant which vegetates between  $10^{\circ}$  C. and  $30^{\circ}$  C. has a maximum at  $20^{\circ}$  C., and if we seek the coefficients of growth corresponding to each successive degree of temperature, we find, as Boussingault has shown, that these coefficients vary for each degree as we depart above or below the temperature most favorable to vegetation.

Similarly De Candolle (1865) has shown that near the minimum and near the maximum temperatures the rate of germination is more difficult, and therefore slower, than at the intermediate or best temperatures; consequently, both in germination and in subsequent vegetation, it is necessary to recognize the fact that calculations of the sums of heat in connection with the study of the geographical distribution of plants are complicated with hypotheses and many sources of error.

Schuebeler (1862) shows that cultivated plants in northern countries have more highly colored flowers, larger and greener leaves, and larger seeds, which are more highly colored and richer in essential oils, than those of southern regions. Bonnier and Flahault (1878) have shown the same facts for uncultivated plants. Both these authors attribute this result to the prolonged action of sunlight, and the latter shows that the variations are exactly proportional to the duration of sunlight. In Flahault's more recent observations he shows that there must necessarily exist a relation between the quantity of carbonic acid decomposed and the quantity of carbonaceous matters formed by the plant, and that in general the sunlight has a very remarkable influence on vegetation since it compensates in a large measure for the deficiency of temperature.

It is, furthermore, to this influence of light that Pauchon attributes the singular fact that plants cultivated in high latitudes are endowed with a vegetating power greater than that of southern countries, so that when transported to the south their seeds ripen sooner than those of the southern plants. This subject has been especially studied by Tisserand in his memoir on vegetation in high latitudes, as cited by Grandeau in his work on nutrition of plants. According to Tisserand a plant behaves in northern latitudes as a more highly perfected machine and one that performs better than southern plants. In regions where it has neither time nor heat it gains in activity and

in the speed with which it perfects its own growth. It seems to Pauchon that we may properly interpret this phenomenon if we admit that a seed transported from the north to the south finds itself in climatic conditions more favorable to the development of the embryo which it contains and of the plant which is to follow. What the action of light loses in duration in proportion as we move toward the equator it gains in intensity. It may be that the cause of this increased activity is due to the larger size of the northern seeds or to their greater richness in the essential oils. Pauchon thinks that the embryo of such a seed should not be compared to a more perfect machine; it is rather an identical machine, but better nourished by the reserve of combustible and nutritive material in the perisperm. Possibly the abundance of essential oils contained within the seed contributes to furnish to the embryo in northern countries the materials for the oxidation that is necessary in order to maintain its temperature during germination and to struggle against the severity of the climate.

Tisserand (1876) has shown that the rye cultivated in northern Norway has not the same chemical composition as that of France and Algeria, and that in general, as we go northward, or as we rise above the level of the sea, or as the temperature lowers without diminishing the quantity of light, we see the starch in the grain increase relatively to the nitrogenous components. Wheat grown at Lynden (North Cape) has a smaller proportion of gluten than the wheat of France, and the latter less than the wheat of Africa. On the other hand, barley raised at Alten, on being sown at Vincennes on the 7th of April by Tisserand, was ripe on the 18th of June, or thirty-seven days in advance of French barley, so that in order to mature it required a sum total of heat far less than the French barley. The reverse is true when southern grains are carried north and sown in colder climates. Therefore, as Marie-Davy has remarked, plants become acclimated more or less rapidly according to their own nature and the extent of the climatic variations that are imposed upon them; the climate produces in them a functional change which corresponds to an organic change the nature of which often escapes our observation. It is therefore not necessary that each phase of vegetation should correspond to a constant sum of heat in very different climates. That which it is important for us to know is what are the limits between which this sum total can vary, for the same species of plant under different climates.

The general fact that the quantity of nitrogen contained in the seeds increases as we approach the warmer climates leads to the hypothesis that the formation of albuminous reserves within the seed takes place in proportion to the temperature, and that the formation of starch and other reserves takes place in proportion to the duration

of the light and the action of the chlorophyl of the leaves. As we pass from the pole to the equator the luminous intensity of the sunlight increases from a hundred to a thousand, but its duration diminishes during the growing season from a hundred at the poles to fifty at the equator. Among the special investigations into the action of sunlight we note that of Timiriazeff (1877), who has shown that a very intense light, after traversing a certain thickness of green-leaf cells, has no further action on the phenomena of the reduction or decomposition of carbonic-acid gas; in other words, it acts the same as darkness would do. On the other hand, Paul Bert, by exposing plants to the action of light which had been sifted through a solution of chlorophyl, invariably found that the development of the green matter of the leaf was completely arrested; inversely, he found the green matter produced to its normal amount when the plant received only light that had been filtered through a solution of iodine in bisulphide of carbon, which solution, as we know, cuts off all visible rays, but allows the red and infra-red to pass through with great freedom. This would seem to demonstrate that chlorophyl is formed by the action of the red portion of the spectrum.

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As to the effect of light on the germination of seeds, Pauchon (1880) gives a critical summary of views by different authors, from which we condense the following:

Miesse (1775), from observation on the Camelina (*Myagrum sativum*), concludes that the seeds grow in darkness the same as in full daylight, and that light does not seem to influence this stage of vegetation.

Sénébier (1782), from observations on seeds of lettuce and beans, some of which were exposed to the full sunlight, others to sunlight after filtering through a thickness of water, others in the dark, and others in red, violet, and yellow light, respectively, reached the conclusion that light was injurious; but his results were not decisive, because of his neglect to observe exactly the temperatures under different conditions.

Ingenhousz (1787) exposed an equal number of mustard seeds in places receiving different amounts of light. He himself concluded that the light of the sun is as injurious to vegetation at the beginning of its life as it is advantageous to vegetation in the fullness of its life. But a more careful consideration of Ingenhousz's experiments shows that the moisture and the temperature in his several localities varied so much as to prevent any serious conclusion as to the action of light itself.

Bertholon (1789), in an article on the effect of electricity, shows

that up to that time it had not been proven whether the germination of the seeds was affected by light or by humidity. His own experiments convinced him that the latter was more important.

Sénébier (1800) made additional experiments on peas and beans, sowing them in sponges, which were kept equally moist, all inclosed under glass covers, so that no evaporation could take place. Some were exposed to sunlight and some were kept in the dark, but those which were in the dark germinated much sooner than those in the light. But in such experiments as these the sources of error are numerous, and the fact that there was no renewal of the air under these covers was especially unfavorable to germination. In fact, Leclerc (1875) has shown that under the influence of mercurial vapor, as it existed in Sénébier's experiments, a large portion of seeds are killed, so that with our present knowledge we can not accept Sénébier's conclusions.

Lefébure (1800), having finally accepted the conclusions of Sénébier and Ingenhousz relative to the injurious influence of light on germination, repeated the experiments, but also observed the temperatures more carefully, and in addition sought to determine the effect of light that had passed through plates of white, green, black, red, and blue glass; but he added little to our knowledge, although he himself concluded that the seeds under white glass were retarded.

Th. de Saussure (1804) endeavored to ascertain whether the influence observed by others was due to light or heat, and he concluded that nothing demonstrates that light has an injurious influence independent of the heat that accompanies it.

Keith (1816) made no observations himself, but controverted the conclusions of De Saussure.

Boitard (1829) sowed the auricula seeds in three flower pots, but the conditions as to temperature and moisture are not sufficiently known to justify us in drawing any conclusion.

A. P. de Candolle (1832) says:

I do not deny that darkness may be useful in germination, but I do deny that it is necessary to think that light has no action on germination. Analogy indicates this, theory confirms it, and experience demonstrates it.

According to De Candolle, light favors the decomposition of carbonic acid, but germination demands the formation of carbonic acid; therefore darkness will favor germination. This theory thus enunciated by De Candolle has been accepted by many authors without proper experimental basis.

Ch. Morren (1832) experimented upon water cresses grown under different colored glasses. He concluded that as darkness favored germination, so the individual colors of the spectrum, acting each by itself, have a special influence that favors germination in such a way that

those colors that have the greatest illuminating power are those that least favor germination.

Ad. Brongniart (1832) announced as the results of his experiments that the retarding influence of light depends not only on the illuminating power of the colored light, but on the relative quantity of white light that passes through the different colored glasses. In all these experiments the seeds were several millimeters below the surface of the soil, so that the colored lights did not affect the seeds directly, but indirectly through the soil whose temperature and moisture and evaporation may easily be of predominating importance.

Ph. A. Pieper (1834), Meyen (1837), Zantedeschi (1846), and Belhomme (1854) have all experimented on the growth of seeds under colored glasses; but the sources of error incident to this method of observation prevent us from drawing any conclusion as to the influence of light itself.

Ville (1865) says that the injurious effect of solar radiation on germination is the result of the heat only and that the effect of the light is inappreciable. For aquatic plants whose seeds germinate in the water, darkness seems decidedly favorable to germination, but it acts only in an indirect manner by preventing the warming of the water and the disengagement of the oxygen that is dissolved in this water.

Charles Darwin (1877) says that certain species of seeds do not grow well when they are exposed to the light, even the diffuse light of a room.

Duchartre (1877) considers the action of darkness as a secondary influence, useful but not at all essential and concerning which there has been too much exaggeration.

Faivre (1879) has shown that the appearance of the primordial latex occurs at a moment when the radicle is only a few millimeters long and when the cotyledons are still inclosed in the seed envelopes and have not yet received the action of light. He notes that under a yellow light obtained by transmitting sunlight through a solution of bichromate of potash the seeds develop their chlorophyl and their latex more rapidly, and consequently have a shorter period of germination than under a blue light obtained by transmitting sunlight through a solution of the ammoniacal oxide of copper.

Detmer (1880) has consecrated an extensive work to the study of the germination of seeds, and states that concerning the action of light we are still ignorant as to whether it is direct—that is to say, whether it stimulates the storing up of new substances in the vegetable tissue or whether, on the contrary, it strengthens the persistence within the cells of some special process having a more or less intimate relation to the phenomena of growth and which can only

proceed in darkness. Detmer adds a few historical references, viz, Humboldt (1794), according to whom seeds sprout more easily in darkness than in light; Fleischer (1851), Heiden (1859), and Nobbe (who all consider solar rays as having no action on the seeds), and, finally, Hunt (1851), who considers that light retards germination.

After this preliminary historical survey, Pauchon communicates the results of his own experiments as to the influence of light on germination on the following twenty-two species of plants:

**Cruciferae:**

*Brassica napus.*  
*Iberis amara.*  
*Lepidium sativum.*  
*Sinapis alba.*  
*Raphanus sativus.*

**Ranunculaceae:**

*Delphinium Consolida.*  
*Nigella sativa.*

**Cucurbitaceae:**

*Cucurbita melo* var. *melon*  
vert.

**Papaveraceae:**

*Papaver somniferum.*

**Euphorbiaceae:**

*Ricinus communis.*

**Gramineae:**

*Zea mays.*

**Leguminosae:**

*Arachis hypogaea.*  
*Dolichos lablab.*

**Rubiacae:**

*Coffea arabica* var. *Rio.*  
*Spilanthes fusea.*  
*Helianthus annuus.*  
*Carthamus tinctorius.*

**Malvaceae:**

*Hibiscus esculentus.*

**Polygonaceae:**

*Fagopyrum esculentum.*

**Linaceae:**

*Linum usitatissimum.*

**Bignoniaceae or Pedaliaceae:**

*Sesamum orientale.*

**Liliaceae:**

*Pancratium maritimum.*

After deducting doubtful results or failures Pauchon gives the following conclusions (see p. 131 of his work above quoted):

(1) In 22 experiments germination occurred first in the light; in 26 experiments it occurred first in the dark.

(2) Five times we obtained duplicate results favorable to the light for the same species of plants (*Arachis*, *Zea mays*, *Dolichos*, *Sinapis*, and *Linum*). Eight times these duplicate results were favorable to specimens kept in the dark (*Helianthus*, *Delphinium*, *Pancratium*, *Ricinus*, and *Papaver*). In one case (*Linum*) two results were obtained favoring light and two favoring darkness.

(3) Among the 22 species of plants used in the experiments 14 gave mixed results equally favorable whether placed in the light or the dark.

(4) Among the 8 other varieties only 1 gave negative results (*Coffea*); 3 gave results favorable to light (*Cucurbita*, *Spilanthes*, and *Carthamus*); 4 gave results favorable to darkness (*Delphinium*, *Pancratium*, *Lepidium*, and *Nigella*).

It appeared to Pauchon impossible to draw any conclusion whatever from these facts. Should we be astonished at this? The problem is certainly much more complex than appears at first sight.



There is every reason to suppose, for example, that the action of light is not the same under all the conditions of temperature which obtained during these experiments. Here again, however, we are confronted by the unknown; because, in order to draw from these researches the consequences which might flow from them it would be necessary to know precisely the thermic conditions favorable to the germination of each species. Unfortunately this is a very important gap to be still filled up, as the work accomplished in this direction gives only approximate results limited to a very small number of different kinds of seeds. On the other hand, looking to facts of another order, mentioned further on in this work, we think that we may be allowed to suppose that the influence of light can only be favorable to germination when it acts at temperatures below that which is most favorable to germination. A considerable number of observations already cited would seem to be in accord with this view of the subject. But unfortunately the many contradictions that we observed in our results do not allow us to accept this opinion as based upon a solid foundation.

Pauchon then goes on as follows:

Another reason, however, induces me to admit, only with many reserves, the results of experiments whose critical epoch is the visible development of the embryo. A method based on this special observation does not appear to me capable of furnishing a really scientific basis for the determination of the question before us. The process of germination is not, in reality, as simple a phenomenon as the greater number of botanists, perhaps too easily, take for granted. Its complexity is even so great that one can not judge of the actual development of the germ of the plant and of the degree of its physiological activity by the external characters observable by the eye, such as the bursting of the spermoderm and the more or less rapid protrusion of the radicle. I do not hesitate to say, according to observations frequently repeated, that this is an empirical process and entirely deceptive in the particular case that we are dealing with. Although it may be capable of furnishing valuable results when we wish to judge of the influence of some one of the fundamental conditions of germination, it becomes utterly insufficient when it is a question of observing the more delicate and fugitive influences, such as that of light. I have, in fact, in the course of chemical researches, given in the next chapter, demonstrated that for the same stage of apparent development the absorption of oxygen by the seeds in the process of germination varies to a large extent with the temperature, and has no relation to the external growth of the embryo. It is, however, not surprising that the development of the embryo continues in the interior of the seed for a much longer time in one seed than in another of identical appearance; the unknown and variable relation between the reserved nutrition and the rudimentary vegetable is probably the explanation of these hitherto unexplained peculiarities.

Although the researches given in this chapter do not give any positive result on the subject of my work, I have preserved them and pub-



lish them here in order to explain to observers the defects of an experimental process to which, in the future, they would themselves have been tempted to resort; this, moreover, seems to me the more useful in that up to this time this danger does not seem to have struck the attention of botanists. On the other hand, my observations contain some new data relative to the temperatures favorable for the germination of certain exotic seeds.

In consequence of the conclusions to which we have thus been led, it would be useless to study the action of the different portions of the solar spectrum on the apparent progress of germination. How, in fact, can we suppose, in view of the contradictory results already obtained for the condition of light and of darkness—that is to say, for the most extreme conditions—that the employment of the same method can reveal a difference of action for the various portions of the spectrum?

Is it then necessary, after this first fruitless attempt, to give up the solution of the problem, or shall we seek it by another and better method? It is this latter alternative that I have adopted in that I have taken for the basis of a new series of observations the variations of a physiological process that, in an almost mathematical manner, measures the germinal activity of the vegetable embryo, namely, the respiration.

After giving the details of his experiments on respiration of plants, Pauchon draws the following conclusions (p. 166):

The laws brought prominently forward by the results of these experiments are:

(1) Light exercises a constant and more or less marked accelerating influence upon the absorption of oxygen by seeds in the process of germination. All the experiments made in a strong light have not, however, the same value in demonstrating this fact. But if we have doubts about the precision of the results furnished by experiments in which germination did not invariably take place (and we believe that we have shown by some preparatory experiments that these results have at least a relative value), this certainly is not the case with experiments Nos. 2 and 8, in which all the seeds did germinate. Thus experiment No. 2 showed in favor of light a result as to the oxygen absorbed twice as great as that given by the seeds placed in the dark. In the same way in experiment No. 8 this superiority reaches to one-third of the quantity of oxygen absorbed by the seeds placed in the dark. Finally, the other experiments, and particularly those classed under Nos. 3, 6, and 7, further confirm the generality of this action of light, which we will, besides, find again in a second series of experiments reported hereafter, several of which have shown unanimity of germination in both cases.

(2) There exists a relation between the degree of light and the quantity of oxygen absorbed. Thus, in a diffuse light this accelerating influence shows itself in a most marked manner when the sky is very clear, and the solar radiation reaches us in its greatest intensity. Such was the case in experiments Nos. 2 and 8. Whenever the sky is cloudy this action is more and more weakened and ceases altogether when the sun is completely veiled, as in stormy weather, so that there is a semiobscurity.

However, in all the experiments where the final result has been favorable to the action of light I have convinced myself that a cloudy sky for twelve hours always showed itself in the amount of the absorption of oxygen in such a manner that the examination of these figures, noted day by day, would almost serve to show the state of the atmosphere during the day which preceded the observation. A very conclusive instance of this action is given us by experiment No. 4 of the second series, in which the state of the sky being carefully observed it showed very marked changes.

(3) The accelerating influence exercised upon seeds exposed to the action of light during the day did not stop at night; it continued to act in the dark with an equal, sometimes even with a greater intensity. I will cite as examples experiments Nos. 3, 4, 6, 7, and 8, when observations made twice a day, morning and evening, allowed of examining the fact I state. How can we explain this persistent action of light? One hypothesis only can be admitted. A portion of the action of the light absorbed by the grain during the day is stored up by it and used by it at night to accelerate its respiration. The proof of this is that the differences of elevation [or quantities of absorbed oxygen] shown in the morning by the instruments for seeds kept in the dark are always below those shown by the instruments and plants in the light. The influence of the light, then, continues for a certain time, at least several hours, even after the light itself has ceased to act; on the other hand, however, this action is not exerted immediately. There is one other phenomenon that we have demonstrated by our experiments. Suppose the sky to be very clear; the differences in favor of light are only apparent after two or three days and become much more marked toward the end of the experiment; that is to say, in proportion as the daily action of sunlight is more and more frequently repeated.

(4) I should also call attention to still another peculiarity, viz, that the differences in the quantities of oxygen absorbed in the dark and in the light were generally much greater at the beginning of these researches than in the later experiments, and particularly in those of the second series. The temperature appears to me to be the only element that varied in these experiments. There must therefore be a more intense respiratory action exercised by light at low temperatures, and this influence would become weakened at high temperatures. This fact would be in entire agreement with the demands of physiology. It is easy of comprehension that a scarcity of heat should be counterbalanced by the action of light, which furnishes for the reaction of the respiratory organs the force that they could not obtain from an insufficient temperature. On the contrary, when the heat is intense the intervention of the light is no longer necessary, the first cause being sufficient to excite the process of germination in the protoplasm of the seeds.

(5) This action of light seems to differ a little according as it acts upon seeds containing albumen or those without albumen. In the case of the albuminous seeds of the castor-oil plant the advantage was much more apparent in favor of those exposed to the light, which advantage appeared to me much less decided for the seeds without albumen, such as the haricot bean. Nevertheless, as the experiments were not invariable in their results, the cause of the variations ob-

served can also be accounted for by attributing them to certain differences in the atmospheric conditions.

(6) The more considerable absorption of oxygen by seeds under the influence of light explains the fact that asparagine (the medium for the conveyance of the reserved albuminous substances in the germination of leguminous plants) only disappears in plants exposed to the light and continues present in those raised in the dark. The comparative researches of Pfeffer (1872) upon the chemical composition of asparagine and other substances showed that asparagine is poorer in carbon and in hydrogen and richer in oxygen than legumine and other albuminoids. The transformation of legumine into asparagine is accompanied by the absorption of a certain quantity of oxygen. On the other hand, it is effected only by the influence of light, the reason being that light increases the quantity of oxygen absorbed, and therefore exerts only an indirect influence on this change, as had already been surmised even when we were not acquainted with the reasons.

(7) Other new and important conclusions become apparent from these experiments and those which follow, and although they have no direct connection with the subject of my work I think it will be well to designate them briefly.

The quantity of oxygen absorbed in a certain space of time by a seed in process of germination varies very considerably according to the temperature; it increases with it, as has been already proved in treating of the respiration of plants in the dark. The general results of my experiments, and particularly of Nos. 9 and 10, leave no doubt of this fact. We can therefore easily understand what errors have been committed by those experimentalists who have given calculations of this absorption of oxygen by certain seeds without taking into consideration the conditions as to temperature. Their figures have no value whatever, particularly in view of a fact stated by me several times already, viz, that the quantity of oxygen absorbed by a seed is not at all in proportion to its apparent development, but, on the contrary, undergoes considerable variation, depending upon the influence of the external agents affecting the phenomenon. According to my observations, this quantity may vary as two to one, or even more, in two plants of identically the same weight, but placed in different thermic conditions from the commencement of their germination to the emerging of the rootlet. From this point of view, then, the plant acts like a complete organism, its respiratory action being accelerated or retarded always, however, within physiological limits, like those of an animal under the influence of certain exterior changes.

Having thus shown that germinating seeds absorb more oxygen in the light than in darkness, Pauchon conducted some experiments to determine the ratio between the oxygen and the carbonic acid, and draws the following conclusions (see page 182 of his work) :

Experiments Nos. 3 and 4 have a real value for the solution of the problem brought forward in this part of my work. As to the partial results given by experiments Nos. 1, 2, and 5, their accuracy can not be doubted; therefore I shall make use of them as confirmatory documents. I must repeat that the numbers used for the proportions of

carbonic acid are a little smaller than they should be in reality, in consequence of peculiarities inherent to the method and already explained; but as this diminution, which is almost insignificant, is equally present in all the quantities, the result is that the numerical quantities are always comparable, although the ratio may be diminished in an inappreciable degree. Finally, I may add that the conclusions which follow are only applicable to plants under precisely the same conditions as those under which my experiments were conducted.

(1) I note, first, that experiments Nos. 3 and 4 confirm in the most precise manner the general fact of the accelerating influence exercised by light upon the absorption of oxygen; but, these experiments having been carried out at a higher mean temperature, the differences in the quantity of oxygen absorbed in the light and in the dark are generally less than in the first series of experiments.

(2) As to the exact relative quantities of carbonic acid exhaled, it was a little more for the castor-oil plant in the dark than in the light, the contrary being the case for the scarlet runner bean. From this we might conclude that the influence of light produces doubly favorable effects upon the germination of the castor-oil plant, (*a*) by increasing the absorption of oxygen and (*b*) by diminishing the exhalation of carbonic acid, thereby increasing the gain of oxygen by reducing the expenditure of carbon and oxygen. (It must not be forgotten, in this explanation, that one volume of carbonic acid gas contains one volume of oxygen.) From this particular point of view the scarlet runner bean seems to be less favored than the castor-oil plant, although the excess of the quantity of carbonic acid exhaled by either placed in the light is nearly insignificant when compared with that exhaled by the same species kept in the dark.

(3) In the dark the ratio  $\frac{\text{CO}_2}{\text{O}}$ , as determined by four experiments divided equally between the seed of the castor-oil plant and those of the haricot bean, was at least a third more in favor of the latter than the ratio obtained for the castor-oil plant. The length of the experiment appears to me to have exercised a certain influence upon this ratio. Thus, for the castor-oil plant the figures reached 0.586 in experiment No. 2, which lasted about four days, and 0.771 in experiment No. 3, which lasted five days. The same was the case with the haricot bean; the result was 1.138 for experiment No. 4, which terminated during the fourth day, and 1.034 for experiment No. 5, which was prolonged until the sixth day. In a word, the prolongation of the experiment

tends to render the ratio  $\frac{\text{CO}_2}{\text{O}}$  equal to unity. With the duration of

the experiment this ratio rises in those cases where it is below 1, but diminishes where it is above 1, until the seed is consumed and the period of vegetation, properly so called, arrives, during which latter time the final limit may be reached when the quantities of oxygen absorbed and the carbonic acid exhaled balance perfectly.

(4) In the light the ratio  $\frac{\text{CO}_2}{\text{O}}$  is about a third more for the

haricot bean than for the castor-oil plant. But the sum obtained in experiment No. 2 was very much below that stated in experiment No. 5. The duration of this experiment and its prolongation until the approach of the vegetating period appears to me to account for this difference. This hypothesis is supported by the results of experiments Nos. 1 and 4, the first having lasted six days and the other less than four.

(5) By comparing the ratio  $\frac{\text{CO}_2}{\text{O}}$  for similar experiments made in the light and in the dark, we see that there is always a difference of a quarter of the value of this ratio in favor of the dark; or, in other words, a seed placed in the dark always exhales more carbonic acid for the same quantity of oxygen absorbed than a seed kept in the light, even although sometimes, as we showed in experiment No. 3, the absolute quantity of carbonic acid exhaled is less in the light than it is in the dark. Finally, while in the light the carbonic acid released is always much less in quantity than the oxygen absorbed, the contrary may be the case in the dark, where the absolute amount of carbonic acid may even exceed the absolute quantity of oxygen, as is proved in experiment No. 4, where the absorption of oxygen 37.36 corresponds to an exhalation of 42.54 of carbonic acid.

(6) In order to consider the influence exerted upon the ratio  $\frac{\text{CO}_2}{\text{O}}$  by the nature of the grain itself under different conditions as to light and darkness, it is only necessary to consult the conclusions which precede, and note the marked differences that distinguish the albuminous and oily seed of the castor oil from the nonalbuminous and starchy haricot bean.

(7) The facts which precede complete the explanation already given of the transformation of legumin into asparagin under the influence of light. In general, the absorption of a greater quantity of oxygen only assures the formation of asparagin in so far as the amount of carbonic acid exhaled is less than the amount of oxygen absorbed; since asparagin is poorer in carbonic acid and richer in oxygen than legumin, all the conditions favorable to that formation are to be found demonstrated in the results of experiment No. 4, with seeds exposed to the light. It is very probable that a portion of the oxygen which had disappeared and that was not found as carbonic acid was absorbed by the albuminoids when forming asparagin, and we know from other sources that this substance seems to form in the majority of seeds during the process of germination.

This absorption of oxygen during the period of germination is still greater in the castor-oil seed than in that of the bean. The oily seed, therefore, seems to be more favored by nature from a physiological point of view.

(8) We might be tempted to compare the ratio  $\frac{\text{CO}_2}{\text{O}}$ , obtained during the time of germination, with the same ratio during the period of vegetation. But the sum for the vegetating epoch has only been precisely fixed in the dark, which for green plants is entirely an abnormal state. As, on the other hand, it is impossible to gauge exactly

the quantity of oxygen absorbed and the amount of carbonic acid exhaled by a plant placed in the light and under natural conditions, it will easily be understood why we refrain from making any comparison until we are in possession of all the data necessary to carry out the calculation.

(9) The facts which precede convince me that the seeds of uncultivated plants germinating in the light are, all other conditions being equal, better distributed than the seeds of cultivated plants; that they possess a greater germinating power, an advantage which increases their chances for ulterior development.



### **Chapter III.**

#### **THE TEMPERATURE OF THE SOIL.**

##### **OBSERVATIONS AT HOUGHTON FARM AND GENEVA, N. Y., BY D. P. PENHALLOW.**

In reference to the value of soil temperatures, Penhallow states (Agr. Sci., Vol. I, p. 78) :

A proper knowledge of the temperature of the soil must serve to guide us in reference to the time of planting particular seeds and the depth at which they should be planted, as determined by the condition and character of the soil. When the farmer gently packs the earth over the planted seed he derives a measure of benefit in the higher temperature of the soil at that place, whereby germination is accelerated. Similarly, we can understand that cultivation during periods of excessive heat must tend to avert some of the evil results otherwise following from an excess of temperature. Moreover, in seasons of great or even of ordinary dryness a judicious system of irrigation must be of the greatest advantage, not only as supplying needed fluids for the general functions of growth, but as reducing the otherwise high temperature of the soil to a degree that is well within the danger limit and consistent with normal growth.

Penhallow also shows from observations at Houghton Farm and at Geneva, N. Y., that all layers of the soil within 3 inches of the surface have temperatures that depend not merely upon absorption of solar heat but also upon the cooling due to radiation and evaporation. The depression due to evaporation amounts to about 8° C. on the average of the warmer half of the year and is even more than this when hot days and strong dry winds produce an excessive evaporation.

##### **OBSERVATIONS BY E. S. GOFF.**

E. S. Goff adduces observations to show that the temperature of the water at the time when it enters into the roots from the soil has some relation to the temperature of the stem of the plant for a short distance above the surface soil, and that the distance up the stem to which this temperature is felt depends upon the rapidity of the flow of the sap, and therefore ultimately on the rapidity of transpiration from the leaves. (Agr. Sci., Vol. I, p. 134.)



## OBSERVATIONS OF TEMPERATURE OF MANURED SOILS IN JAPAN BY GEORGESON.

Soil temperature must to some extent be affected by the heat given out by decaying manure and vegetation. On this subject Mr. C. C. Georgeson describes some experiments being made at Tokyo, Japan (*Agr. Sci.*, Vol. I, p. 251), from which it appears that the temperature immediately after applying the manure was from 2° to 5° F. higher than in the unmanured soil, and this excess steadily diminished, but was still appreciable at the end of two months. The 2° of excess occurred when the manure was applied at the rate of 10 tons per acre, and the 5° of excess when applied at a rate of 80 tons per acre.

## INFLUENCE OF RAIN ON TEMPERATURE OF THE SOIL AT MUNICH. (K. SINGER.)

The study of the earth temperatures at considerable depths is a problem for terrestrial physics, but for agricultural purposes we need only consider the temperature of the soil within 4 or at most 8 feet. The work of Karl Singer (1890) is sufficiently instructive to justify the presentation of his general results for use in studying the phænological phenomena of Europe. In a simple diagram Singer summarizes at a glance the mean temperature of the soil at any depth between 1 and 7 meters for any day of the year, as it results from an average of thirty years of observations at the observatory at Bogenhausen, near Munich, Bavaria. The series of observations includes, in fact, four sets of earth thermometers, two of which were on the northwest side of the observatory and the other two on the southeast side; the diagram and the following summary of results relate to the average of the pair on the southeast side. Each set of thermometers consisted of five, whose bulbs were buried at depths of 4, 8, 12, 16, and 20 Bavarian feet, respectively, or 1.2, 2.4, 3.6, 4.8, and 5.9 meters, respectively. The lines given in this diagram are thermal isopleths, viz, curves of equal temperature for successive depths and days, the days being represented by vertical lines and the depths by the horizontal lines. The following paragraphs express the general results of Singer's work as far as it bears upon the growth of plants:

(1) The normal mean temperature of the earth for twenty-five years (1861–1885) at Bogenhausen, near Munich, at certain depths, is as follows:

Thermometer.	Depth.		Mean temperature.	Amplitude.
	Bavarian feet.	Meters.		
No. I.....	4.2	1.3	9.18	11.64
No. II.....	8.2	2.5	9.16	7.64
No. III.....	12.2	3.6	9.12	5.24
No. IV.....	16.2	4.8	9.12	3.48
No. V.....	20.2	6.0	9.06	2.12

(2) The mean temperature of the earth at a depth of about 1 meter below the surface exceeds the mean temperature of the air [at a meter above the surface] by more than 2°. The important influence of the considerable altitude above sea level of the place of observation is to be recognized in this result.

(3) The decrease of the annual amplitude with increasing depth for the adopted interval of 4 Bavarian feet, or 1.17 meters, amounts to 12.18° C., or very nearly one-third of the original amplitude of the atmospheric temperature. The amplitude  $\Delta P$  in centigrade degrees at the depth  $P$  in meters is represented by  $\log \Delta P = 1.2620 - 0.1508 P$ . Whence we compute the amplitudes given in the last column of the preceding table.

(4) The epoch of the occurrence of the extreme and mean temperatures for the highest thermometer, No. I, are: Minimum, 2d of March; first mean, 21st May; maximum, 24th August; second mean, 15th November. These are therefore separated from each other by intervals of about 2½, 3, 2½, 3½ months, respectively. For each step downward of 4 feet, or 1.2 meters, in depth, the occurrence of the epoch of extreme temperature is retarded on an average 21 days and that of the mean temperature 24 days; therefore an almost uniform distribution of these dates is brought about down to a depth of 20.2 feet, or 6 meters, where the minimum occurs on the 23d of May, the first mean on the 24th August; the maximum 17th November, and the second mean on the 24th February.

(5) The actual temperatures of the ground from 1861 to 1889, at the upper stage of 4.2 feet, or 1.3 meters, or thermometer No. I, did not fall below 2° C. or rise above 17° C. At the lower levels they ranged between 4° and 14°, 5° and 13°, 6° and 12°, 7° and 11°, respectively.

(6) By a careful consideration of the state of the weather it is possible in every case to account for the connection between the fluctuations of the temperature of the air and that of the earth.

The following generalizations refer to the climate of the South Bavarian Plateau only and to the four seasons of the year:

(7) In mild and, as usual, rainy, winter months, there is no material rise in the temperature of the earth relative to the average temperature curves, particularly at great depths, but generally a lowering of temperature.

(8) Mild, and at the same time dry, winters are associated with a tendency of the earth temperature to rise above the average.

(9) The earth temperatures exhibit a tendency to fall, if not already too low, during winters in which, with alternate freezing and thawing, the mean temperature is below the normal.

(10) In the same way even a covering of snow can only to a limited extent prevent the cooling of the earth when severe cold follows the mild and rainy weather of the first part of winter.

(11) In continuous severe winters, on the contrary, when even December generally brings a permanent covering of snow, the negative departure of the earth temperature is either limited to the higher strata or is unimportant.

(12) A warm spring, which, as a rule, brings only a moderate quantity of rain, causes a relatively decided rise of the earth temperature.

(13) When a cold and rainy late winter is directly succeeded by warm spring months, the temperatures of only the upper strata of the ground rise, while those of the lower strata may fall still further below their normal values.

(14) In certain warm and at the same time rainy springs the earth temperatures remain on an average unchanged with respect to the normal [or the cold rain counterbalances the warm weather. C. A.]

(15) An exceptionally cold spring, which is generally distinguished by heavy snows, is, with few exceptions, accompanied, and to a considerable depth, by a notable lowering of the temperature of the ground in comparison with its normal temperature.

(16) In cold and at the same time dry spring weather the relative lowering of the temperature of the ground will generally be inconsiderable if it has not been preceded by an immediate very rainy season.

(17) A warm summer is always accompanied by a high temperature of the ground or by a rise of its temperature. The increase is the more decided the more the excess in the temperature of the air is accompanied by a large quantity of rain or has been immediately preceded by it. In warm and comparatively dry summers the rise of the earth's temperature does not perceptibly exceed the normal.

(18) The relative lowness of the temperature of the soil which follows without exception a cool summer generally extends down only to a comparatively moderate depth, scarcely to 4 meters. Those months in which we find it extending to 6 meters will be found to have been at the same time rainy months.

(19) A warm autumn, with very few exceptions, causes a corresponding small rise in the temperature of the soil, but this may even, on the contrary, become a fall when the late autumn, by reason of much rain, resembles a mild type of winter.

(20) Low air temperature is generally accompanied in autumn by an excess of rain, the consequence of which, as regularly and frequently observed, is a falling in the temperature of the earth.

(21) In the rarer cases of cool and dry autumns there is observed only a very inconsiderable influence on the temperature of the earth.

(22) The dampness of the soil is (under the climatic influences prevailing in Munich) sufficient to allow the variations in the temperature of the air in winter and spring to exercise a decided influence upon those of the soil, whereas in summer an excess of rain would be

necessary to accomplish this, and that, too, to a greater degree if the soil be covered with vegetation. The phenomena of autumn generally resemble closely those of summer.

(23) In general the fluctuations in the temperature of the earth are not less dependent on the precipitation than on the variations in the temperature of the air.

#### **SOIL TEMPERATURES AS AFFECTED BY SURFACE SLOPE AND COVERING (WOLLNY).**

In reference to the effect of the slope of the earth's surface on the temperature of the soil, Wollny (1888, p. 364) has made an extensive series of measurements at Munich from which he draws the following conclusions in continuation of those published by him in 1883. His temperatures were measured bihourly at a depth of 15 centimeters under both fallow soil and grass sod; the differences referred to amounted to 3° and 4° F. in individual cases, but on the average to scarcely 1° F.

(1) That soil whose exposure is toward the south is the warmest, then comes the east, then the west, and finally the north exposure.

(2) The southern exposure is warmer in proportion as the inclination to the horizon is greater.

(3) The difference of temperature between the north and south exposure is much greater than between east and west.

(4) The difference in the warming of the soil for north and south exposures is greater in proportion as the surfaces have a greater inclination.

Wollny (1888, p. 415) has also investigated the influence of the covering of straw and chaff on the temperature and moisture of the soil. He finds the following conclusions:

(1) That at a depth of 10 centimeters the naked soil is warmed more with rising air temperatures and is cooled more with falling air temperatures than under any one of the different forms of straw covering.

(2) That the variations in the temperature within the straw litter are very much less than in the earth.

(3) That the earth is in general somewhat colder than the material of which the litter is made, except when the latter is moss.

(4) That among the various materials forming a litter the pine needles are warmed the most, the oak leaves and the fir-tree needles are less warm, while the litter of moss is the coldest.

The different temperatures observed were as follows, on the average of the months April to September: Pine needles, 16.93° C.; oak leaves, 16.62° C.; fir needles, 16.34° C.; the naked soil at a depth of 10 centimeters, 16.18° C.; moss, 15.95° C.

The difference between the morning and evening temperatures shows:

(1) That the cooling during the night and the warming during the day is appreciably larger for the naked earth than for the various kinds of litter.

(2) That the pine needles warm up most during the day and the moss warms up least; that the fir needles cool most during the night and the pine needles least.

The power of retaining moisture varies with the different kinds of litter as follows:

(1) Any litter of forest leaves or needles is moister than the earth, but the moss is less moist than the earth; the gradation is from oak leaves, the highest, through fir needles to moss, the lowest.

With regard to evaporation Wollny shows that the naked earth loses a greater quantity of moisture by evaporation than do the various kinds of litter.

(2) That the moss litter evaporates the most, but the litter of forest leaves the least.

(3) That the quantity of evaporation is greater the thinner the layer of the litter.

In general, then, the litters of leaves and of pine needles give up the rain water that falls upon them to the ground beneath in larger proportion, but still continue to be very moist because they lose, relatively, little water by evaporation; furthermore, that the moss litter is distinguished by large variations in its contained water because it has on the one hand a large capacity for water and on the other hand a very considerable evaporating power.

#### **SOIL TEMPERATURES OBSERVED AT GREENWICH, ENGLAND.**

Among the limited number of long-continued series of observations of temperatures of soil near the surface is that maintained at Greenwich Observatory, England, since June, 1846. This series embraces observations at considerable depths that will not interest the student of agriculture, but we reproduce in the following table the results of observations at 1 inch in depth, as given in the annual volumes of the Greenwich Observatory for 1878, and as given in J. D. Everett's memoir of 1860. These soil temperatures can be used in any subsequent study of English crops throughout the southern half of England or in analogous climates.

*Monthly and annual means of noonday readings of a Fahrenheit thermometer whose bulb is 1 inch below the surface of the soil at Greenwich Observatory.*

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual mean.
	°	°	°	°	°	°	°	°	°	°	°	°	°
1847.....	37.8	38.0	42.9	47.2	58.0	61.1	67.4	64.7	58.9	54.5	48.7	44.5	51.81
1848.....	37.4	44.1	44.6	49.5	61.6	61.7	65.0	60.8	58.8	53.5	45.5	45.5	52.33
1849.....	41.5	43.6	44.3	46.3	56.5	63.3	65.0	65.2	61.8	53.0	46.5	41.1	52.34
1850.....	38.7	44.4	41.9	50.4	53.0	64.1	65.2	63.0	58.7	49.5	48.7	42.7	51.52
1851.....	44.2	42.7	44.0	48.5	54.8	62.2	63.8	65.5	60.0	54.7	41.2	42.2	51.98
1852.....	42.8	42.0	43.0	49.9	55.1	59.4	71.0	65.2	61.1	50.2	50.4	48.0	53.18
1853.....	44.3	37.0	41.8	47.4	55.7	62.3	63.2	64.1	60.3	55.1	44.9	38.0	51.18
1854.....	40.6	41.6	45.3	52.7	54.2	59.8	64.4	64.6	61.6	52.9	44.1	42.9	52.06
1855.....	38.4	33.4	41.0	48.9	52.9	61.3	65.6	66.0	60.9	54.7	44.3	38.3	50.47
1856.....	41.5	43.3	41.7	50.4	52.6	63.0	64.8	66.7	59.0	54.5	43.9	41.9	51.94
1857.....	38.9	40.7	43.7	48.3	57.6	65.6	67.0	67.9	62.5	55.2	48.8	46.6	53.57
1858.....	39.6	37.8	42.2	49.6	54.3	68.6	64.5	66.0	62.7	54.2	42.2	42.4	52.01
1859.....	42.4	43.5	47.3	49.3	55.8	64.4	70.7	66.7	59.7	54.4	44.3	39.3	53.15
1860.....	40.9	37.4	42.1	45.2	56.7	58.2	61.3	60.4	57.0	52.4	44.0	39.9	49.62
1861.....	35.5	42.6	44.6	47.7	54.9	63.2	64.6	66.2	60.3	57.5	43.9	42.6	51.97
1862.....	40.7	42.9	45.6	50.6	57.8	60.0	62.6	63.5	60.6	54.3	42.7	44.0	52.11
1863.....	43.2	43.2	45.0	51.1	54.3	60.5	64.0	63.9	57.6	54.3	48.0	45.6	52.56
1864.....	39.6	39.0	43.2	50.0	56.3	60.0	63.2	62.2	59.5	54.0	45.4	41.6	51.17
1865.....	38.8	38.9	39.3	53.3	57.8	64.4	66.1	62.5	65.6	54.7	47.5	45.1	51.83
1866.....	44.1	43.1	42.0	50.3	52.8	63.3	65.0	61.7	59.0	55.2	47.2	44.9	52.38
1867.....	38.3	46.1	40.7	49.9	55.9	61.4	62.6	64.1	60.5	52.6	45.2	39.9	51.43
1868.....	39.4	44.5	45.9	50.5	59.8	64.3	69.9	66.7	63.0	52.2	45.0	47.0	54.02
1869.....	43.0	46.8	40.8	51.5	54.3	58.6	66.2	63.2	60.9	52.4	45.8	40.5	52.00
1870.....	40.1	38.1	42.5	50.0	56.1	64.2	67.1	63.8	54.6	52.9	44.3	38.1	51.32
1871.....	36.2	42.0	45.0	49.6	54.2	58.4	63.7	66.6	60.7	52.0	41.2	39.2	50.73
1872.....	41.6	44.6	45.0	49.8	53.4	61.5	66.9	63.9	60.6	50.8	47.1	43.0	52.86
1873.....	42.8	36.4	42.4	48.5	53.3	61.2	66.0	65.2	57.7	51.4	45.7	42.7	51.11
Average .....	40.38	41.40	43.25	49.50	55.54	62.08	65.44	64.46	60.21	53.45	45.43	42.50	51.97

#### SOIL TEMPERATURES OBSERVED AT BROOKINGS, S. DAK.

Among the agricultural experiment stations in the United States whose work will be used in this preliminary report are some whose observations of the temperature of the soil will be needed for comparison with the observations on the growth of plants and resulting crops or for demonstrations of the relations between the temperature of the air and of the soil. The following table gives for Brookings, S. Dak., the daily maximum readings of the thermometer in the air and shade, the daily rainfall, the maximum temperatures of the soil at depths of 2 inches and 12 inches as far as published in Experiment Station Bulletin No. 6 for a portion of the summer of 1888. These figures show that in summer and for the growing season generally the temperature of the soil near the surface is higher than that of the air in the shade only when the sun shines on it, and that it is lower than the temperature of the air in the shade only when the radiation cools it at nighttime or when the rain falls in the daytime and is for a short time followed by rapid evaporation. The average



of the maximum temperatures of the air, less the temperatures of the soil at 2 p. m. at a depth of 2 inches was  $2.3^{\circ}$  F. in July, 1888, and  $3^{\circ}$  F. in August, 1888. On the other hand, the average value of the maximum temperature of the air, less the temperature of the soil at 2 p. m. at a depth of 12 inches was  $12^{\circ}$  F. for the observations here given, scattered through July and August, 1888.

*Temperatures at Brookings, S. Dak.*

[Lat.  $44^{\circ} 20'$  N.; long.  $96^{\circ} 40'$  W.; altitude, 1,000 feet.]

Date, 1888.	Maximum air temperature.	Daily rainfall.	Soil temperatures (readings at 2 p. m.).		Date, 1888.	Maximum air temperature.	Daily rainfall.	Soil temperatures (readings at 2 p. m.).	
			Depth 2 inches.	Depth 12 inches.				Depth 2 inches.	Depth 12 inches.
	$^{\circ}$ F.	Inch.	$^{\circ}$ F.	$^{\circ}$ F.		$^{\circ}$ F.	Inch.	$^{\circ}$ F.	$^{\circ}$ F.
July 13	69.0	0.00	69	-----	Aug. 9	63.0	0.0	63	60
14	81.5	.11	81	-----	10	60.0	.40	-----	-----
15	81.0	.0	77	-----	11	62.0	.01	-----	-----
16	82.0	.0	81	-----	12	74.0	.0	-----	-----
17	79.0	.0	71	-----	13	79.0	.0	-----	-----
19	86.0	.0	82	-----	14	75.0	.50	67	-----
23	82.0	.0	84	-----	15	69.0	.20	63	-----
24	83.0	.0	86	-----	16	72.0	.0	71	-----
25	82.5	.0	84	-----	17	73.0	.0	72	-----
26	89.0	.0	83	-----	18	82.0	.0	71	-----
27	88.0	.0	81	-----	19	72.0	.42	-----	-----
28	94.0	.0	85	67	20	80.0	.01	-----	-----
29	89.0	.0	70	70	21	79.0	.0	70	-----
30	101.0	.23	103	76	22	82.0	.0	78	78
31	73.0	.0	87	65	23	83.0	.0	76	71
Aug. 1	77.0	.0	75	67	24	89.0	.0	77	70
2	91.0	.0	85	68	25	94.0	.0	82	75
3	83.0	.0	93	70	26	84.0	.0	-----	-----
4	89.0	.0	85	71	27	89.0	.0	84	78
5	79.0	1.27	-----	-----	28	82.0	.0	-----	-----
6	76.0	.12	83	68	29	94.0	.0	-----	-----
7	71.0	.0	77	67	30	78.0	.0	86	71
8	76.0	.28	63	64	31	69.0	.0	83	68

It would appear that the reading of the soil temperature is frequently omitted when rain falls; this is a bad practice, but the records suffice to show us that in this dry country and during the summer time the maximum surface temperatures of the soil will not differ much from the maximum temperatures of the air, while the soil temperatures at 12 inches will closely follow the mean temperature of the air. The latter mean, viz, one-half the sum of the maximum and minimum record for any day is greater than the mean temperature of the layers of soil at 2 and 12 inches depth, as observed at 2 p. m., by about  $6^{\circ}$  F.



### SOIL TEMPERATURES OBSERVED AT AUBURN, ALA.

As an illustration of soil temperatures in a southern locality I have chosen the following record for 1889 at Auburn, Ala., where the agricultural experiment station has maintained three sets of buried thermometers, two of them in sandy soils on hills and one in moist bottom land near the banks of a small stream. It appears from these records that the difference in temperature in the growing season between the so-called "cold wet" and "warm dry" soils averages but a few degrees; in fact, I doubt whether it is appreciable from observations having the accuracy of those here given. Thus at 3 inches depth and during the warm half of the year the maximum temperatures on the hill average 1° F. above those in the bottom land, while the minimum temperatures on the hill average 2° F. colder than those of the bottom lands. The temperatures here given are the averages of the maxima and minima and are taken from successive monthly reports and from Bulletin No. 18 of the Alabama Agricultural Experiment Station. In these, as at most other United States stations, the correction for the temperature of the long stem of the thermometer still remains to be applied. A comparison of the temperature at 3 inches depth with the maximum and minimum air temperature shows that the soil is warmer than the air in the daytime from April to October, inclusive, and warmer than the air at the minimum temperatures throughout the year. This latter is true for the minimum temperatures of the soil down to a depth of 96 inches, but the excess of maxima temperatures of the soil over those of the air during the daytime in summer ceases a little below 6 inches. Evidently the temperature of the soil is sufficiently high to allow of the growth of some form of vegetation throughout the year.

*Extremes and means of soil temperatures for 1889, as observed at Auburn, Ala.*

[Lat. 32°.6 N.; long. 85°.4 W.; altitude, 732 feet.]

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
<i>Air temperatures.</i>	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
Mean air temperature...	46.9	46.3	54.7	62.5	70.1	76.1	80.7	77.6	74.8	62.3	53.1	57.8
Mean radiation temperature .....	39.7	36.8	43.2	55.6	57.2	65.8	70.0	67.5	65.2	49.5	42.9	45.5
Maximum air temperature .....	67.0	75.0	76.0	82.0	89.0	91.5	98.0	92.5	93.0	82.0	76.0	74.0
Minimum air temperature .....	23.0	16.5	30.0	38.0	45.0	46.0	67.5	63.0	48.0	38.0	24.0	29.0
Maximum terrestrial radiation temperature ..	51.0	66.5	54.0	62.0	63.0	74.0	73.5	72.5	78.0	60.0	60.0	59.5
Minimum terrestrial radiation temperature ..	21.0	24.0	32.0	37.0	43.0	43.0	60.0	62.0	48.0	36.0	22.0	30.5

*Extremes and means of soil temperatures for 1889, etc.—Continued.*

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
<i>Soil temperature.</i>												
<b>SANDY SOIL ON A HILL; OFTEN CULTIVATED DURING CROPS.</b>												
3-inch depth:	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
Maximum.....	63.5	60.0	73.5	82.5	92.5	98.0	101.5	95.0	96.5	84.5	69.5	69.0
Minimum.....	33.5	32.0	37.0	48.5	52.0	52.0	71.5	69.5	54.5	45.0	35.0	35.0
6-inch depth:												
Maximum.....	61.0	76.5	68.5	79.5	89.0	92.0	98.0	92.5	92.5	82.5	68.5	65.0
Minimum.....	35.5	34.5	39.0	50.0	55.0	55.0	73.5	70.5	57.5	48.0	37.0	37.5
24-inch depth:												
Maximum.....	52.5	57.0	58.5	67.0	76.5	80.0	86.0	82.0	89.5	74.0	65.5	60.0
Minimum.....	46.5	44.0	49.0	58.0	64.5	68.5	77.0	78.0	72.0	62.5	52.0	50.0
48-inch depth:												
Maximum.....	53.5	53.0	56.5	63.0	71.5	75.0	79.5	79.0	84.5	74.5	69.0	60.5
Minimum.....	51.5	48.0	50.5	56.5	63.0	69.5	74.5	77.0	75.0	67.0	58.0	56.5
96-inch depth:												
Maximum.....	59.5	56.5	56.0	60.5	62.5	69.0	73.0	73.5	76.5	74.5	70.0	65.0
Minimum.....	56.5	54.5	54.5	54.0	60.0	65.5	69.0	73.0	73.5	70.5	64.0	62.0
<b>BOTTOM LAND ON BANK OF SMALL STREAM.</b>												
3-inch depth:												
Maximum.....	60.5	67.0	69.0	80.5	92.5	95.0	101.0	96.0	96.0	84.5	71.5	69.5
Minimum.....	35.5	35.0	41.5	47.5	55.0	55.0	74.0	70.5	56.5	45.0	34.0	34.0
6-inch depth:												
Maximum.....	58.5	65.0	66.5	79.5	88.0	91.0	97.5	93.0	92.0	82.0	69.0	65.0
Minimum.....	39.0	38.0	44.0	52.0	59.0	58.0	76.0	73.0	60.0	49.0	37.0	36.0
24-inch depth:												
Maximum.....	54.0	57.5	58.0	67.5	76.0	80.0	85.5	82.0	82.5	74.5	66.0	60.0
Minimum.....	48.5	46.0	51.0	58.5	65.0	69.5	77.0	78.5	72.5	63.0	52.5	50.0
48-inch depth:												
Maximum.....	54.5	54.0	57.0	64.0	71.0	75.0	79.5	79.0	79.0	75.0	68.0	61.0
Minimum.....	52.5	50.5	51.5	57.0	63.5	69.5	74.5	77.0	75.0	67.5	59.0	57.0

**SOIL TEMPERATURES OBSERVED AT PENDLETON, OREG.**

Among the United States experiment stations for which soil temperatures have been published, I quote the following observations made by Mr. P. Zahner, voluntary observer at Pendleton, Oreg., (lat. 45°.7 N.; long. 112°.2 W.; altitude, 1,122 feet), because it represents a climate so different from that found in the same latitude east of the Rocky Mountains. A number of observations of diurnal periodicity are given by Zahner, and a shorter series is at hand for Corvallis, Oreg. (lat. 44°.5 N.; altitude, 150 feet). The comparison between these shows that the Pendleton air and soil are appreciably warmer than the Corvallis in July, August, and September, but colder in November and probably also in December. In general the maximum soil temperature at Pendleton at all depths follows that of the

daily maximum air temperature. Rainfall lowers the temperature of the soil, as on March 18, 1890, at 8 inches depth by 2° F., but at 24 inches depth by 0.5° F. At 12 inches depth the soil was not frozen throughout the year, but at 8 inches it was frozen up to the 7th of March. The soil temperatures were read daily at 3 p. m.; the soil was naturally dry and light, and was covered with a thin grass. The thermometers were maximums and minimums, apparently read from above ground without being disturbed in their positions.

*Observations at Pendleton, Oreg., in 1890.*

[From the Monthly Reports of the Oregon State Weather Bureau.]

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
<i>Air temperature.</i>	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
Absolute maximum temperature.....	60.0	58.0	70.0	89.0	91.0	100.0	105.0	99.0	90.0	73.0	68.0
Absolute minimum temperature.....	-16.0	-13.0	10.0	21.0	30.0	36.0	40.0	44.0	26.0	24.0	14.0
Mean of maximum temperature.....	29.1	39.7	51.5	67.9	75.0	76.6	87.2	88.5	80.6	64.5	57.2
Mean of minimum temperature.....	13.0	20.5	32.5	36.6	45.2	49.4	50.5	49.1	39.5	34.8	23.6
Monthly mean temperature.....	21.0	30.1	42.0	52.2	60.1	63.0	68.8	68.8	60.0	49.6	40.4
<i>Precipitation.</i>											
Total monthly rainfall.....	1.19	1.52	2.04	0.17	1.51	1.80	0.08	0.07	0.27	0.63	0.01
<i>Soil temperature.</i>											
4-inch depth:											
Maximum .....	38.0	49.0	55.0	76.0	81.0	90.0	92.0	86.0	80.0	64.0	53.0
Minimum .....	16.0	26.0	30.0	48.0	60.0	61.0	74.0	75.0	62.0	53.0	40.0
Mean .....	26.7	37.3	44.9	62.2	72.3	74.2	84.6	83.3	73.2	57.4	45.8
8-inch depth:											
Maximum .....	33.0	44.0	49.0	68.0	72.0	80.0	83.0	78.0	71.0	60.0	49.0
Minimum .....	20.0	29.0	30.0	48.0	59.0	61.0	72.0	71.0	64.0	50.0	38.0
Mean .....	27.8	36.6	40.9	55.3	66.3	68.4	77.6	75.8	66.5	53.7	43.2
12-inch depth:											
Maximum .....	34.0	41.0	46.0	62.0	67.0	71.0	78.0	85.0	70.0	63.0	51.0
Minimum .....	27.0	33.0	33.0	46.0	58.0	60.0	69.0	71.0	64.0	51.0	40.0
Mean .....	30.4	37.1	39.8	52.2	63.1	65.8	73.7	73.3	65.7	54.7	45.2
24-inch depth:											
Maximum .....	38.0	40.0	45.0	58.0	64.0	66.0	74.0	73.0	70.0	64.0	54.0
Minimum .....	33.0	35.0	36.0	45.0	58.0	61.0	68.0	71.0	64.0	54.0	44.0
Mean .....	34.6	38.1	40.1	50.1	60.9	63.7	70.7	71.7	66.7	57.3	48.5

<sup>a</sup> Inches.

**SOIL TEMPERATURES OBSERVED AT MONTREAL, CANADA.**

As illustrating temperatures of the ground in a very cold locality, I quote the work of Messrs. C. H. McLeod and D. P. Penhallow, of McGill College Observatory, Montreal, who have maintained a series of observations of the temperature of the earth by Becquerel's method, in which the temperature of a coil of wire in the laboratory is brought to equality with the temperature of a similar coil buried in the

earth. The following table gives the mean temperature for the ten-day periods ending on the dates given in column 1 and at a depth of 1 foot below the surface of the ground. Temperatures are given by them for other depths, as also for the air; the total rain and snow is also given. An investigation of the connection between earth temperature and the development of vegetation is being carried on by them, but as no results have as yet been published I give merely their soil temperatures at a depth of 1 foot, which usually agree, within a degree centigrade, with the average temperature of the air for ten days.

*Mean temperature of the soil at a depth of 1 foot for periods of ten days at  
Montreal, Canada.*

End of period.	Average soil tem- pera- tures.	End of period.	Average soil tem- pera- tures.	End of period.	Average soil tem- pera- tures.
1888.	° C.	1889—Continued.	° C.	1890—Continued.	° C.
November 11 .....	6.3	July 9 .....	21.1	March 6 .....	1.0
November 21 .....	2.3	July 19 .....	20.4	March 16 .....	0.7
December 1 .....	0.4	July 29 .....	21.5	March 26 .....	0.4
December 11 .....	0.9	August 8 .....	21.2	April 5 .....	0.5
December 21 .....	0.8	August 18 .....	18.7	April 15 .....	0.6
December 31 .....	0.4	August 28 .....	18.9	April 25 .....	5.3
		September 7 .....	19.6	May 5 .....	7.4
1889.		September 17 .....	18.4	May 15 .....	9.1
January 10 .....	0.5	September 27 .....	13.6	May 25 .....	11.7
January 20 .....	0.6	October 7 .....	11.0	June 4 .....	15.0
January 30 .....	0.2	October 17 .....	7.1	June 14 .....	15.5
February 9 .....	0.2	October 27 .....	5.0	June 24 .....	17.6
February 19 .....	−0.4	November 6 .....	4.7	July 4 .....	21.1
March 1 .....	−0.1	November 16 .....	4.3	July 14 .....	20.7
March 11 .....	−0.3	November 26 .....	3.0	July 24 .....	20.7
March 21 .....	−0.2	December 6 .....	1.2	August 3 .....	21.7
March 31 .....	−0.5	December 16 .....	1.0	August 13 .....	21.9
April 10 .....	−0.5	December 26 .....	0.9	August 23 .....	18.7
April 20 .....	3.7			September 2 .....	16.5
April 30 .....	6.4	1890.		September 12 .....	17.2
May 10 .....	12.7	January 5 .....	1.3	September 22 .....	14.9
May 20 .....	15.3	January 15 .....	1.9	October 2 .....	11.1
May 30 .....	14.7	January 25 .....	1.4	October 12 .....	10.1
June 9 .....	15.5	February 4 .....	1.1	October 22 .....	8.8
June 19 .....	18.8	February 14 .....	0.8	November 1 .....	6.8
June 29 .....	19.2	February 24 .....	0.8		

This series seems to show the powerful influence of a snow covering to keep the ground from cooling to very low temperatures during the winter. The minimum temperatures at 1 foot depth were −0.5° F. during the twenty days March 22 to April 10, 1889, and +0.4° F. during the ten days March 17 to 26, 1890.

## METHODS OF MEASURING SOIL TEMPERATURES.

As it is very important that there should be numerous observations of soil temperature available for agricultural study, and as many persons are deterred by the expensiveness of the deep-earth thermometers, I would call attention to the fact that agriculture does not need to consider temperatures at depths below 4 feet and that the inexpensive, excellent system of thermometers, made by Green, of New York, has been recognized as the standard at stations in the United States; but for accuracy and convenience nothing can exceed the thermophone devised by Henry E. Warren and George C. Whipple, of the Massachusetts Institute of Technology.

Several methods of measuring deep-earth temperatures have been most thoroughly studied in the memoirs of Wild and Leyst, of St. Petersburg, a summary of which I have prepared and will submit at another time.

The soil thermometers constructed by Green are made in accordance with suggestions made by Milton Whitney, of the South Carolina Experiment Station, and have been used by him.

Whitney has published a description of this new self-registering soil thermometer as follows (see *Agr. Sci.*, Vol. I, p. 253; Vol. III, p. 261) :

This is a modification of Six's form of thermometer in which the maximum and minimum temperatures are registered in one and the same instrument. The essential features of the thermometers are as follows: A cylindrical bulb 6 inches long, filled with alcohol. The bulb is protected by a somewhat larger cylindrical metal tube, containing numerous holes, and is to be placed 3 inches below the surface of the soil—i. e., so that the bulb will extend vertically between the depths 3 and 9 inches, respectively, in the soil. The tube carrying the alcohol extends some 6 or 8 inches above the surface of the ground, when it bends twice at right angles and descends again to the surface, bends at right angles twice, crossing the main stem, and is carried up about 6 or 8 inches again, where it terminates in a bulb partially filled with alcohol. The lower bend in this stem carries a column of mercury which is drawn back toward the bulb when the alcohol contracts, and pushes a steel index up to the minimum temperature on a scale which reads downward. This index is held supported in the alcohol by a little spring when the alcohol expands and the mercury leaves it, while another index is pushed up to the maximum temperature by the other end of the column of mercury. The indices are set by the help of a magnet.

The advantages claimed for this instrument are that it gives at once, without any calculation, the mean temperature of a definite depth of soil, for which we now use at least three thermometers, while it gives in addition the maximum and minimum temperatures, and need only be read once a day instead of three times, as at present. \* \* \*

Thermometers can be made, of course, with bulbs longer or shorter than the one described. We adopted the length of 6 inches placed 3 inches below the surface, as in our experience that represents a layer of soil in which most of the roots of the cotton plants are contained. We expect to distribute a number of these instruments through the State [South Carolina] and have records kept for us near signal-service stations in our typical soils—a method which could hardly have been arranged with the old form. The instrument is mounted on a neat metal backing, and is made by H. J. Green, of New York. It cost \$10 without packing or express charges. The great trouble about the instrument is the danger in transportation of having the index get down in the mercury column. For this reason it has to be transported in a box on gimbals to swing freely within a larger box, so that it will always remain upright. We had such a box made, capable of carrying eight or ten instruments, for \$5.

From experiments at Houghton Farm (Agr. Sci., Vol. II, p. 50) F. E. Emory finds that the thermoelectric couple and galvanometer, as used by Becquerel, consumed much time and was frequently useless owing to atmospheric electricity and ground currents. Short-stem graduated thermometers, with bulbs immersed in oil and fastened at the lower end of a light wooden rod, gave good results when the temperature at the thermometer was not warmer than that of the overlying soil or the atmosphere; otherwise a circulation of air takes place. He finds that the telethermometer, giving a continuous record, answers his needs, but we know nothing of its accuracy.

T. C. Mendenhall (1885) describes a modified form of thermometer for observing the temperature of the soil at any depth, which he calls the "differential resistance thermometer." Experiments with this instrument at Washington, D. C., have shown him that it is much less troublesome than Becquerel's electric method, but still too troublesome to be recommended to any but persons accustomed to electric measurements. Mendenhall's arrangement consists essentially in utilizing the varying resistance of a platinum wire which extends from the upper end of an ordinary mercurial thermometer down into its bulb. The total resistance diminishes as the temperature rises and allows the current to flow through less platinum but more mercury. The changes in the resistance are measured by the galvanometer, but he hopes to substitute for this the telephone, which will make the apparatus more convenient for general use.

[It is desirable that this or Becquerel's method or the thermophone be provided in connection with the ordinary buried long-stem thermometers in order that by an annual or more frequent set of comparative observations the changes in the zero point of ordinary thermometers may be detected.—C. A.]



## Chapter IV.

### THE INFLUENCE OF SUNSHINE ON ASSIMILATION AND TRANSPIRATION.

#### CHEMISTRY OF ASSIMILATION (ABBOTT).

The atmosphere is composed of about 79 per cent of nitrogen and 21 per cent of oxygen when we consider their volumes, but 77 per cent of nitrogen and 23 per cent of oxygen when we consider their relative weights. With these gases there are mixed small quantities of carbonic-acid gas, ammonia, hydrocarbons, and other impurities. With this "dry atmosphere" there is intermixed a very variable quantity of aqueous vapor or moisture, which in extreme cases may amount to as much as 5 per cent, by weight, of the dry air. These are the elements that are to be compounded by sunshine and heat in the laboratory of vegetation.

By respiration the leaves of plants, when in the dark, absorb oxygen from the air and set free carbonic-acid gas.

By assimilation, as shown by Garreau, these same leaves in the sunshine absorb carbonic-acid gas from the air and set free oxygen, retaining the carbon in new compounds. Assimilation is a process of greater intensity than respiration. Respiration is a process analogous in its results to that occurring within every animal organism, but assimilation is a process peculiar to the plant life.

By transpiration the leaves rid themselves of the superfluous water that, as sap, has served its purpose in the process of assimilation by bringing nourishment from the soil and delivering it up to the cells of the plant; a small portion of the nourishment and of the water may have been absorbed by the cells in the trunk of the tree, the stem of the vine, or the stalk of the grain and grass, but the majority of the water is removed by transpiration at the surface of the leaves in order to make room for fresh supplies of sap. Some water always remains in the cells of the seeds and grains until they are dried after maturity, but a well-dried crop contains relatively little water. This transpiration is stimulated by, and almost entirely depends upon, the action of sunshine on the leaves; it precedes evaporation.

Evaporation is not transpiration; the former takes place from the surface of water existing either in the moist earth or in films on leaf surface or in larger masses, while transpiration takes place through the cell wall and is a process of dialysis, an endosmosis and exosmosis



by which the cell takes in the sap, retains what it needs, and then gets rid of the water and the dissolved substances which it does not need. Thus the cell wall thickens and enlarges and the contents of the cell increase. The sap enters the cell from that side of the cell which is turned toward the interior of the plant or adjacent cells, and the rejected water penetrates the cell wall on that side of the cell which is exposed to the open air, and especially on that side exposed to the sunshine; having reached the outer surface of the cell wall on this side of the cell it is then evaporated. This endosmosis by which the sap enters the cell on one side, and the exosmosis by which it leaves the cell on the opposite side, constitute the fundamental mechanics of all vital activities; the chemistry of animal and vegetable life differs from the ordinary chemistry of the laboratory in that the former studies the behavior of the cell wall toward the molecule, while the latter studies the behavior of the molecule toward the molecule. An interesting contribution to the development of this idea of the chemistry of the action of the cell is contained in two papers by Miss Abbott (now Mrs. Michael, of Philadelphia), published in 1887 in the Journal of the Franklin Institute; from the second paper I take the following extract:

The botanical classifications based upon morphology are so frequently unsatisfactory that efforts in some directions have been made to introduce other methods.

There has been comparatively little study of the chemical principles of plants from a purely botanical view. It promises to become a new field of research.

The Leguminosæ are conspicuous as furnishing us with important dyes, e. g., indigo, logwood, catechin. The former is obtained principally from different species of the genus *Indigofera*, and logwood from the *Hæmatoxylon campechianum*, but catechin from the *Acacia catechu*.

The discovery of hæmatoxylon in the *Saraca indica* illustrates very well how this plant, in its chemical as well as botanical character, is related to the *Hæmatoxylon campechianum*; also, I found a substance like catechin in the *Saraca*. This compound is found in the Acacias, to which class *Saraca* is related by its chemical position as well as botanically. Saponin is found in both of these plants, as well as in many other plants of the Leguminosæ. The Leguminosæ come under the middle plane of multiplicity of floral elements, and the presence of saponin in these plants was to be expected. \* \* \*

From many of the facts above stated, it may be inferred that the chemical compounds of plants do not occur at random. Each stage of growth and development has its own particular chemistry.

# SUNSHINE AND TRANSPIRATION (DEHERAIN AND MARIE-DAVY).

Studies in the transpiration of plants were made in England as early as 1691 by S. H. Woodward, who experimented on aquatic plants. He showed that the consumption of water by the plant, or the weight of water evaporated from it, varied within narrow limits, while the growth of the plant under the same temperature and sunshine, varied according to the amount of nourishment in the water; thus of pure spring water 170 grains had to be evaporated in order to make an increase of 1 grain in the weight of the plant, but only 96 grains of the rich water of the Thames was required to make the same increase in the weight of the plant.

In 1848 Guettard, experimenting upon a creeping nightshade, showed that a plant kept in a warm place without sunshine would transpire less than one in a colder place with sunshine.

Deherain, as quoted by Marie Davy (1880, p. 231) introduced the leaves or stems of a living plant into a tube suitably closed; under these circumstances, by reason of the small, calm space of air surrounding the leaves, the evaporation in the ordinary sense would be inappreciable, but the transpired water was found to increase the weight of the tube, as shown in the accompanying table.

*Sunshine and transpiration.*

Plant.	Exposure.	Temperature.	Weight of water transpired per hour per gram weight of leaf.
		° C.	Gram.
Wheat .....	Sunshine.....	28	0.882
Do.....	Diffuse light.....	22	.177
Do.....	Darkness.....	22	.011
Barley .....	Sunshine.....	19	.742
Do.....	Diffuse light.....	16	.180
Do.....	Darkness.....	16	.023
Wheat .....	Sunshine.....	22	.718
Do.....	Darkness.....	16	.023
Do.....	Sunshine.....	28	.708
Do.....	Diffuse light.....	22	.060
Do.....	Darkness.....	22	.007

The effect of sunshine in stimulating transpiration is very clearly seen by a study of these figures. The small transpiration from the leaf when kept in darkness is supposed to be, at least in part, due to a persistency of the stimulus given to the plant by the light; so that, as is well known, the growth of the plant goes on at its maximum rate in the late afternoons, sometimes even after sunset, and does not attain its minimum until early morning.

Deherain also arranged the following experiments showing the effect of temperature. Some living leaves of wheat were kept within a glass tube which lay in a water bath at a uniform temperature of 15° C. and the following measurements taken:

In full sunshine the transpiration was 0.939 gram of water per hour per gram weight of leaf.

In darkness the transpiration was 0.016 gram of water per hour per gram weight of leaf.

The water bath was then reduced to a temperature of 0° C., and the temperature of the leaf within the tube must therefore have been at the freezing point. In this condition the transpiration in full sunshine was 1.088 grams of water per hour per gram weight of leaf.

Thus leaves in sunshine in free air at 28° C. and leaves in the air at 15° C., and again in the water bath at 0° C., give us the transpiration under these conditions 0.882, 0.939, 1.088, respectively. It is evident that this transpiration is not due to evaporation alone, else it would be independent of sunshine and depend wholly on heat; the decided differences here shown must be attributed to the special excitement of the cell by the solar radiation.

Marie Davy gives for July 24 and 25, 1877, the following record from a self-registering apparatus showing the diurnal periodicity of the transpiration from the leaves of four plants of haricot beans which were watered daily at 7 p. m.:

*Diurnal periodicity of transpiration.*

Hour.	Transpi- ration.	Hour.	Transpi- ration.	Hour.	Transpi- ration.
7 to 8 p. m. ....	4	4 to 5 a. m. ....	8	1 to 2 p. m. ....	120
8 to 9 p. m. ....	2	5 to 6 a. m. ....	82	2 to 3 p. m. ....	95
9 to 10 p. m. ....	2	6 to 7 a. m. ....	76	3 to 4 p. m. ....	67
10 to 11 p. m. ....	4	7 to 8 a. m. ....	90	4 to 5 p. m. ....	44
11 p. m. to 12 midnight.	4	8 to 9 a. m. ....	86	5 to 6 p. m. ....	25
12 midnight to 1 a. m..	4	9 to 10 a. m. ....	128	6 to 7 p. m. ....	10
1 to 2 a. m. ....	2	10 to 11 a. m. ....	153	7 to 8 p. m. ....	4
2 to 3 a. m. ....	4	11 a. m. to 12 noon ...	179		
3 to 4 a. m. ....	4	12 noon to 1 p. m. ....	143		

These same four plants showed the transpiration day by day, as given in the first column of the following table (Marie Davy, 1880, p. 239). The third and fourth columns, respectively, show the relation of this transpiration to the daily mean temperature and the daily mean radiation, as shown by the conjugate thermometers.

*Insolation and transpiration for kidney beans at Montsouris.*

Date, 1877.	Weight of transpired water.	Weight of transpired water divided by—		Date, 1877.	Weight of transpired water.	Weight of transpired water divided by—	
		Mean temperature.	Mean actinometric degrees.			Mean temperature.	Mean actinometric degrees.
	<i>Grams.</i>				<i>Grams.</i>		
July 16.....	0.686	4.1	1.16	July 24.....	0.706	3.8	2.00
17.....	0.422	2.6	1.36	25.....	1.300	7.1	2.17
18.....	0.727	4.4	1.21	26.....	0.991	5.8	1.92
19.....	0.543	2.9	1.23	27.....	1.255	6.7	2.46
20.....	0.577	3.3	1.56	28.....	1.426	7.8	2.64
21.....	1.127	9.1	1.24	29.....	1.277	5.9	2.97
22.....	1.606	6.2	1.81	30.....	2.167	7.6	3.55
23.....	1.204	5.4	1.88	31.....	2.710	8.4	3.15

The figures in the above table are influenced by the quantity of moisture in the soil; therefore Marie Davy occasionally omitted the evening watering, and the transpiration for the day after such omission was smaller. In general, Marie Davy concludes that the relation between transpiration and temperature is very variable from day to day, while that between transpiration and radiation is very regular, a regularity that would very probably be heightened if the cloudiness and the evaporating power of the wind, as depending on its dryness and velocity, had been considered. The belief is that sunshine excites the contraction of the stomata of the leaves and thus stimulates transpiration; but the stomata can not exude water to a greater extent than as supplied by the roots; therefore the transpiration is limited by the humidity of the soil adjacent to the roots. Thus on the 30th the radiation averaged 45.5 actinometric degrees, and the plant transpired 2.167 grams of water; on the 31st the radiation was 64.1 and the transpiration correspondingly increased to 2.710 grams; but on this day the reserve moisture in the soil was drawn upon very heavily, and in the evening the leaves of the plant were flabby and drooping and evidently wilting for the want of moisture.

The results by Deherain at temperatures of 15° C. and 0° C. and those by Marie Davy seem to demonstrate satisfactorily the slight influence of the temperature of the air as such upon transpiration.

Daubeney (1836), Deherain, and Wiesner have studied the effect of radiation in different parts of the spectrum, and their work shows that the radiations that are absorbed by chlorophyl, the so-called chlorophyl-absorption bands, are those that are efficient in stimulating transpiration; also that xanthophyl acts similarly, but weaker than chlorophyl; that the violet and ultraviolet have no appreciable influence; that the ultrared rays have an appreciable action, but feebler than the visible rays between the red and blue, notwithstand-

ing that their heating effect is usually greater than those of the visible spectrum.

The laws of growth or vitality are the laws of physics and mechanics and chemistry as applied to living cells. The changes that go on slowly in the plant are not the same as would go on rapidly in large masses of the same chemicals when treated as in the ordinary chemical laboratory. In the plant small masses are confined within the transparent walls of the cells until that subtle influence which we call radiation can do its work in bringing about new combinations of the atoms. It matters not whether we consider the radiation as an orthogonal vibration, as in light, or a promiscuous interpenetration of the molecules, as in heat, or a radial vibration, as in the waves of sound; whatever view we take of it, or whatever the details may be, even if it be a rhythmic breaking up and re-formation of the molecules, the general characteristic of radiation is an extremely rapid motion along the molecules and atoms of matter. Therefore, by radiation we understand energy or momentum in the minute atoms that go to make up the molecules and the masses that we deal with; this implies that work is done by one atom upon its neighbor, which work, according to its style, we call light, heat, evaporation, etc. Assimilation and transpiration are among the forms of work in the growth of the plant that are due to the molecular energy contained in sunshine, and it is essential to progress in agriculture that there be kept a continuous register of the intensity and nature of the solar radiations that reach the plant. But this is a difficult problem, whose satisfactory solution has not yet been attained, although the work of Violle, Bunsen and Roscoe, Marie Davy, Marchand, Langley, Rowland, Hutchins, and many others have marked out the methods which seem most promising.

#### **ANNUAL DISTRIBUTION OF SUNSHINE.**

Humboldt (1845), in his chapter on "Climate," after comparing the climates and fruits of Europe, says:

These comparisons demonstrate how important is the diversity of the distribution of heat throughout the different seasons of the year for the same mean annual temperature, as far as concerns vegetation and the culture of the fields and orchards, and as well as regards our own well-being as a consequence of these conditions.

The lines which I call isochimenal and isothermal (lines of equal temperature for winter and summer) are not parallel to the isothermal lines (lines of equal annual temperature) in those countries where— notwithstanding the myrtle grows wild in its natural state, and where no snow falls during the winter—the temperature of summer and fall scarcely suffices to bring apples to full maturity. If to give a potable wine the vine shuns the islands and nearly all sea coasts, even those of the west, the cause is not only in the moderate heat of summer upon the seashore, a circumstance which is shown by thermometers exposed

in the open air and in the shade, but it consists still more in the difference between direct and diffused light, between a clear sky and one veiled with clouds, a difference which is still unappreciated, although its efficaciousness may be proved by other phenomena, as, for example, the union of a mixture of chlorine and hydrogen.

Humboldt adds:

I have endeavored for a long time to call the attention of scientists and physiologists to this difference; in other words, to the yet unmeasured heat which direct light develops locally in the cell of the living plant. (Cosmos, t. I, pp. 347-349.)

### **TOTAL QUANTITY OF HEAT REQUIRED TO RIPEN GRAIN.**

Boussingault (1834), in his Rural Economy, computes the total quantity of heat required to ripen grain by multiplying the mean daily temperature of the air in the shade in centigrade degrees by the duration, in days, of the process of vegetation. This product is known as the number of "day degrees" that the plant has experienced or has required for the development from sowing to maturity. (See Annual Report Chief Signal Officer for 1881, p. 1208.) Boussingault's results are given in the accompanying table:

*Day degrees required at different latitudes.*

Plant and place.	Latitudes north.	Duration of the culture.	Mean air temperature during culture.	Product of the days by the temperature.
<b>Autumn wheat:</b>	° ' <i>Days.</i>		° C.	<i>Day deg.</i>
Alsace .....	48 48	187	15.0	2 055
Alais .....	44 7	146	14.4	2 092
Kingston .....	41 50	122	17.2	2 098
<b>Summer wheat:</b>				
Alsace .....	48 48	181	15.8	2 069
Kingston .....	41 50	106	20.0	2 120
Cincinnati .....	89 6	137	15.7	2 151
Truxillo .....	9 00	100	22.8	2 208
Quinchuqui .....	0 14	181	14.0	2 230
<b>Winter barley:</b>				
Alsace .....	48 48	122	14.0	1 708
Alais .....	44 7	137	13.1	1 795
Kingston .....	41 50	92	19.0	1 738
Santa Fe .....	4 35	122	14.7	1 793
Cumbal .....	0 00	168	10.7	1 798

The above table shows that the total quantity of heat required increases as the latitude diminishes.

### **THE SUNSHINE AND HEAT REQUIRED TO RIPEN GRAIN.**

Tisserand (1875) modifies Boussingault's hypothesis that growth varies with heat and time, but adopts the rule that the work done by a plant can be represented by the product of the mean temperature

by the number of hours of sunshine, only rejecting the useless night-time, just as one would reject the useless low temperature. In the absence of sunshine records he uses the number of hours between sunrise and sunset, or the duration of diffuse sunshine, and obtains for spring wheat and barley the data given in the accompanying table, where the last column may be said to give "sunshine hour degrees."

Sunshine hour degrees.

Plant and locality.	Latitude north.	Hours of possible sunshine.	Average daily temperature.	Sunshine hour degrees (temperature × sunshine).
Spring wheat:	° ' /		° C.	
Alsace .....	48 30	1 906	15.0	29 900
Christiania .....	59 9	1 795	15.4	27 643
Halsno .....	59 47	2 187	13.0	28 431
Bodo .....	67 17	2 376	11.3	26 848
Strand .....	68 46	2 472	10.9	26 944
Skibotten .....	69 28	2 486	10.7	26 600
Barley:				
Alsace .....	48 30	1 416	19.0	26 900
Christiania .....	59 9	1 620	15.5	25 125
Halsno .....	59 47	2 035	11.7	23 809
Bodo .....	67 17	2 138	11.0	23 000
Skibotten .....	69 28	2 188	10.7	23 000
Do .....	69 28	1 824	12.7	22 876

We see that the sunshine hour degrees diminish as the latitude increases. This diminution ought to be rather more rapid in proportion as the actual state of the cloudy atmosphere approaches the theoretical state of absolute clear sky.

Thus Halsno and Bodo, localities which have very nearly the same soil, the same altitude, the same orientation, the same distance from the sea, but which are more or less under the influence of the aqueous vapor coming from the Gulf Stream, have a cloudiness during the evolution of wheat of 5.6 and 7; during that of oats, 5.4 and 7; where 0 represents perfect freedom from clouds and 10 completely covered.

If records of cloudiness could have been used, the numbers in the last column would have been computed like those in the following table:

	Possible sunshine.	Cloudiness.	Clear sky.		Average daily temperature.	Sunshine.
Spring wheat:	Hours.	Tenths.	Per cent.	Hours.	Degrees.	Hours.
Halsno .....	2,187	5.6	44	962	13.0	12,508
Bodo .....	2,376	7.0	30	713	11.3	7,865
Barley:						
Halsno .....	2,035	5.4	46	936	11.7	10,951
Bodo .....	2,138	7.0	30	641	11.0	7,051



## THE SUNSHINE AND HEAT REQUIRED TO FORM CHLOROPHYLL.

After considering the preceding data Marié-Davy (1880, p. 221) presents the following as his views:

It is the chlorophyll or green coloring matter in the cells of the green leaves that alone has the property of decomposing the carbonic acid of the air. It utilizes the sunlight, but also requires a certain temperature, which may be given to it either from the air or from the sunshine itself, so that we may say that ordinarily in nature the sunshine both warms the chlorophyll by means of the red rays and enables it to decompose carbonic acid by means of the yellow rays. The decomposing action of the chlorophyll only becomes appreciable at a certain minimum temperature, which is about  $15^{\circ}$  C. when the temperature is rising. It attains its maximum activity at about  $30^{\circ}$  C., and as the temperature cools it retains an appreciable activity at about  $10^{\circ}$  C. These figures are obtained by experiments of Cloëz and Gratiolet on water plants in the full sunshine. On the other hand, Boussingault obtains  $1.5^{\circ}$  and  $3.5^{\circ}$  C. as the lower limits of temperature for the ordinary Gramineæ, but these plants were in the sunshine, and if his temperature observations had been made in the shade they would have given lower figures than these, so that undoubtedly the Gramineæ can assimilate and grow when the temperature of the air in the shade is below freezing. On the other hand, Sachs find that when the illumination is below a certain minimum, which varies with the plant and with the temperature, the color of the chlorophyll is a clearer yellow tint, and for temperatures below a certain minimum which varies with the plant it remains colorless, notwithstanding the most brilliant sunshine. Thus in 1862 the exceptionally low temperature of the month of June was sufficient to prevent the development of new leaves on the stems of maize, cucumbers, and beans, so that all these remained yellow and only became green subsequently with warmer weather and better sunshine.

The pale leaves of a sprouting bean became green in a few hours under a temperature of  $30^{\circ}$  to  $33^{\circ}$  C., but this happened only in the sunlight, for at the same temperature in the darkness they remained yellow. At a temperature of from  $17^{\circ}$  to  $20^{\circ}$  C. the greening of the leaf went on much more slowly; at  $8^{\circ}$  and  $10^{\circ}$  C. there was only a trace at the end of seven hours; below  $6^{\circ}$  C. the leaves remained fifteen days without greening.

Similarly the pale shoots of maize, even at a temperature of  $24^{\circ}$  to  $35^{\circ}$  C., did not become colored in the darkness, but in the feeble light of the interior of a room a green effect was visible at the end of an hour and a half, and at the end of seven hours the leaves were all green and of normal appearance. At a temperature between  $16^{\circ}$  and  $17^{\circ}$  C. the first traces of color were visible at the end of five hours.

But at temperatures of  $13^{\circ}$  and  $14^{\circ}$  C. nothing was seen even at the end of seven hours. At a temperature below  $6^{\circ}$  the leaves remained uncolored for fifteen days in the diffuse light of the room.

Again, the pale shoots of cabbage placed in the window, and therefore in full sunshine and at temperatures of  $13^{\circ}$  or  $14^{\circ}$  C., became green at the end of twenty-four hours; but under temperatures of  $3^{\circ}$  to  $5^{\circ}$  C. only traces of green color were seen at the end of three days, and the coloration was not complete until at the end of seven days.

Herve Mangon, by employing the electric light in place of sunlight, has arrived at similar results for rye. Marié-Davy, by the use of a single gaslight, has obtained similar results for the strawberry plant. Similarly De Candolle caused mustard and other plants to become green by the light of four argand lamps.

Evidently a very feeble light suffices to produce the greening, for the feeble individual effects accumulate and add together; but when a bright light is used secondary reactions set in, transforming and utilizing the chlorophyll itself. The light that determines the production of the chlorophyll and its green color also proceeds to destroy the chlorophyll. Thus the direct light of the sun rapidly decolors the alcoholic extract of chlorophyll, while diffuse light acts more slowly; but in a living plant the action of light is different, since it may become so intense for a special plant that the destruction of the chlorophyll may go on faster than its formation. If a green plant is carried into a dark room the chlorophyll ceases to form and a gradual process of destruction, or rather of transformation and assimilation, goes on until the plant becomes pale yellow. This mutability of chlorophyll makes it the essential medium through which the plant is nourished.

Draper, Desains, and others have shown that the chlorophyll absorbs certain rays of the spectrum; that is to say, that the work of forming and transforming chlorophyll is accomplished by means of radiations that have a certain velocity of vibration or a certain wave length, and that they are mostly those that form the red, orange, yellow, green, and blue portions of the spectrum. Awaiting a more detailed study of this phenomenon, we must at present adopt the general rule that the variation in efficiency of each of these agents is approximately proportional to the variation in the total energy of the solar radiation, although our present knowledge points to the conclusion that a radiant beam generally contains specific active wave lengths in proportions and intensities that have no necessary relation to each other.

### **INFLUENCE OF ABSORBENT MEDIA ON CHLOROPHYLL.**

The action of sunlight on the chlorophyll within the cell is not materially modified if the light passes first through layers of cells that do not contain chlorophyll, such as those of the red colored cabbage leaf, since in those cells, as in yellow cells and others, the radiation that is absorbed is not to any extent that special radiation which the chlorophyll absorbs. The absorption of light by the yellow cells of the yellow leaves of an alder bush was examined by T. W. Engelmann (*Agr. Sci.*, Vol. II, p. 139), who found that these absorbed most from the middle of the spectrum and least at either end, whereas the chlorophyll absorption is complementary to this. He also found that the green leaves of the alder bush, when exposed to the light side by side with the yellow leaves, set free far more oxygen than these, so that it seems probable that if the yellow cells contain only pure xanthophyll there assimilating power would be zero.

### **INFLUENCE ON THE SUPPLY OF SAP.**

The action of sunshine in producing or altering the colors of fruits, especially the black Hamburg grape, has been experimentally studied by Laurent. (*Agr. Sci.*, Vol. IV, p. 147.) Bunches of immature grapes quite shielded from the sunlight ripened, colored, and flavored as usual, but bunches whose food supply had been cut off by ringing the base of the stock supporting the bunch, and then also kept in the dark, remained green, small, and sour. Bunches that had been subjected to the ringing process, but which were exposed to the sunlight, produced berries of normal size, some reddish and others green and of an acid flavor. He concludes that the coloring matter of grapes may be formed in the absence of sunshine, provided a sufficient supply of nourishment be at hand, but if this supply be arrested then the color remains imperfect.

### **CLIMATE AND THE LOCATION OF CHLOROPHYLL CELLS.**

Guntz (1886) has studied the anatomical structure of the leaves of cereals and grasses in their relations to locality and climate. This connection is infinitely complex. Among other items brought out by him we note that the green assimilating organism consists of many cells of various shapes and in most cases fills the spaces between the nerves of the leaves; in tropical grasses the green cells occur most in the inclosing sheath, but in the grasses of the steppes it lies on either side of the grooves or ridges. The intercellular gaps, according as they are larger or smaller, indicate a moist or a dry soil and, equally so, a moist or dry atmosphere. The bast in the leaves of the grasses serves primarily to strengthen the whole structure, but the bast increases with the dryness of the locality, and its proportional distribution is an appropriate, indirect indication of the climate.

### THE INFLUENCE OF CLOUD AND FOG.

There are some parasitic plants, says Marié-Davy (1881 and 1882), that require only moisture and warmth in order to vegetate. They mature and propagate while entirely cut off from sunlight, but they derive this power from organic matter or cells that have been previously formed by the action of sunshine upon the plant on which the parasite itself feeds.

Similarly certain bulbous plants will flower and mature in darkness, but in doing so the bulb itself is wholly consumed and dies; the plant lives on organic matter that was elaborated and stored up by its parent and predecessor in preceding years when it had sunshine to do the work for it. If a new bulb is to be formed as a basis for the flowering of the next year then the present bulb and plant must be allowed the necessary sunlight.

Similarly the seeds of the annuals sprout and nourish their little plants out of their own substance while still beneath the surface of the earth, but when the shoots reach up to the sunshine this furnishes the energy needed for the work of assimilation and the plant begins to live on the soil and the air. The roots can only send up to the leaf an inorganic sap with possibly here and there an organic cell scattered through it which has penetrated into the roots, as it were, by accident; it is the sunshine that sets these organic cells into activity, causing them to grow and to multiply.

If a plant in vigorous growth is removed from sunshine to darkness it draws upon its own reserves and lives upon itself as long as possible. In darkness the plant transforms the organic products that are at its disposition, but it can not manufacture any new ones. On the contrary, it consumes itself and its dry weight steadily diminishes. The experiments of Boussingault on seeds, those of Sachs on plants and seeds, those of Pagnoul on the beet, and of Macagno on the grapevine all confirm this general principle. The observations of the latter show that as between two sets of vines, one exposed to the sun and the other covered with a dark cloth, the growth of the latter, as measured by the amount of solid and gaseous material, was not 10 per cent of the growth of the vine in the sunshine. Other vines under a white cloth showed a growth of 80 per cent, thus apparently proving that the differences were not due to anything else except sunshine.

Pagnoul experimented upon sugar beets, some of which were covered by glass that had been blackened on the inside; this coating of lampblack is ordinarily said to absorb heat, but it would be more proper to say that it transforms all the short waves of the sunshine into long waves so that the plants beneath it receive neither ultra-violet nor visual rays, but only the ultra-red, or long, heat waves. Therefore beneath the black glass the temperature was somewhat warmer than beneath the transparent glass and the latter warmer

than the free air. The results of analysis at the end of the experiments showed that under the transparent glass the weight of the roots was the same as in the free air, but the weight of the leaf was much more, the weight of the sugar much less, and the weight of the nitrous salts much greater. Under the black glass the weight of the roots was 4 per cent of that in the free air, and the weight of the leaves was about 25 per cent, the weight of sugar 2 per cent, and the weight of the salts 8 per cent, thus demonstrating an almost complete stoppage of the vital processes.

Evidently the action of these artificial coverings on the experimental plants is perfectly analogous to the action of cloud and fog in nature.

It is commonly said that on the seacoast the action of the salt brine blown by the wind up over the land is to stunt or prevent vegetable growth, but the same effect must be produced by the absence of sunlight in those regions where fog and cloud prevail.

#### INFLUENCE OF SHADE ON DEVELOPMENT.

According to Marchand (1875, p. 130), the influence of a diminution of sunlight on the development of the plant is apparent in the relative growth of plants on sunny and cloudy days or in sunny and shady places, but the matter was brought to exact measurement by Hellriegel. His experiments on barley gave him these results:

*Weight of harvest of barley.*

Plants raised—	Straw.	Seed.
	<i>Pounds.</i>	<i>Pounds.</i>
In the open air .....	11.44	10.10
	10.99	11.19
In a greenhouse in direct sunshine .....	6.72	2.86
	6.82	3.26
In a greenhouse in diffuse light only .....	3.40	-----
	2.59	-----

We see here that plants living in the greenhouse, receiving sunlight that has traversed the glass, have experienced a considerable diminution in their development as compared with those in the free air which experienced the full chemical force of the sunshine. The plants living under glass and in the diffuse light developed only a small quantity of stalk and did not perfect the seed at all.

#### INFLUENCE OF LONG AND SHORT WAVES OF LIGHT.

Vöchting (1887) investigated the formation of tubers as influenced especially by sunlight. Sachs had maintained that the germination was entirely prevented, or at least went on very slowly, if sunlight,

i. e., short waves, had access to the tubers. Vochting finds that, although the light does delay the growth and diminishes the distance between the tubers, still the supply of water is the important factor. (Wollny, X, p. 230.)

Sachs (1887), as the result of experiments on the effect of ultra-violet radiation upon the formation of buds, states that these rays exert on the green leaves (in addition to the assimilation produced by the yellow and neighboring rays) still another effect that consists in the development of particles that contribute to the formation of blossoms. These bud-forming particles move from the leaves into those parts of the plant where they are to bring about their own development into buds. We therefore now know of three different portions of the solar spectrum having very different physiological influences: The yellow and neighboring rays, which bring about the transformation of carbonic acid or the formation of starch; the blue and visible violet, that act as stimulants to motion; the ultraviolet rays, that produce in the green leaves the material for the formation of buds. (Wollny, X, p. 230.)

#### **INFLUENCE OF DRYNESS AND SUNLIGHT ON DEVELOPMENT OF TUBERS.**

In the climate of Germany the flowering of different varieties of potatoes is very much restricted. Only a small number of varieties flower regularly and bear fruit, whereas in Chile the plant flowers abundantly, but the tubers are small; in other words, in the Temperate Zone the formation of tubers is favored at the expense of fertilization; the energy of the one process increases while the other diminishes.

Knight and Langenthal have found that by detaching the young tubers they increase the blooming, and on the other hand, by cutting off the flowers they increase the development of the tubers, thereby largely increasing the harvest. Wollny, in 1886, experimented on four plats, each for many varieties of potatoes. He found that cutting off the flowers increased the crop of tubers as to number, size, and weight, but that something depended upon the time of cropping the flowers, which is best done a considerable time before they arrive at maturity. It seems probable that dryness and sunlight stimulate the formation of flowers, but humidity and cloudiness, at least up to a certain limit, stimulate the formation of tubers. This harmonizes with some recent results obtained by Sachs, who has shown that the ultraviolet rays stimulate the flowering. (Agr. Sci., Vol. II, p. 273.)



## Chapter V.

### THE METHODS OF MEASURING DIRECT OR DIFFUSE SUNSHINE AS TO INTENSITY OR DURATION.

Sunshine may be measured as to its quality or wave length, its intensity, or its duration. The methods used in measuring either of these must be understood in order to intelligently compare the published observations with phænological phenomena. The following section considers some of the methods of measuring or registering the duration or intensity of sunshine, or the intensity of the skylight, at least in so far as these have been used in agricultural studies.

#### THEORETICAL RELATION OF DIRECT AND DIFFUSED SUNSHINE.

The relative intensity of any radiation may be measured by its heat or light or chemical effect. The insolation received by a horizontal surface, whether directly from the sun or diffusely from the sky, is subject in a general way to calculation, but the irregularities introduced by haze and clouds can not be so calculated and must be observed daily. The following table gives, for a clear blue sky, the values obtained by Clausius for the radiation (S) that falls upon a horizontal surface directly from the sun, and in the third column the diffuse radiation (C) that falls from the whole sky upon that same surface; the total radiation (S+C) is the sum of these two. If, however, the surface is normal to the sunlight, instead of horizontal, it receives the quantity in the fifth column (I) directly from the sun, and (c) which is less than the quantity (C) from the sky, depending upon the altitude of the sun, the total being, as before, the sum of these (I+c). The study of these columns shows us the maximum and minimum amounts of sunshine that may fall upon a given leaf surface, since a leaf will in general be in some position to receive the full sunshine normally to its surface, while others will be horizontal, or vertical, or in the shade, and receive only a part of the diffuse light from the sky.

It is assumed by Radau, in his actinometry (1877), as also by Marié-Davy, that the bright and black bulb thermometers in vacuo, or the so-called "conjugate thermometers," give us the total radiation (C+I) as for the horizontal surface, and that this is the quantity in which vegetation is interested.



Relative quantities of direct and diffused sunshine.

Sun's altitude.	Horizontal surface.			Normal surface.		
	Sun (S).	Sky (C).	Total (S+C).	Sun (I).	Sky (c).	Total (I+c).
°						
10	0.08	0.07	0.10	0.19	0.04	0.23
15	.09	.09	.18	.33	.05	.38
20	.15	.11	.26	.43	.06	.49
25	.21	.13	.34	.51	.08	.59
30	.28	.14	.42	.56	.10	.66
35	.35	.15	.50	.61	.11	.72
40	.41	.16	.57	.64	.12	.76
50	.53	.17	.69	.69	.14	.83
60	.62	.18	.80	.72	.16	.88
70	.69	.18	.87	.74	.17	.91
80	.74	.18	.92	.75	.18	.93
90	.75	.19	.94	.75	.19	.94

TOTAL INSOLATION, DIRECT AND DIFFUSED.

The value of the intensity of the direct solar rays incident normally to any unit surface, as determined by the absolute actinometers of Pouillet, Violle, and others, is not so applicable to the study of the growth of plants as is the sum of the radiation from the sky and other surroundings of the plant, added to the direct solar radiation. Comparative measures made in 1866 by Roscoe, at Manchester; Baker, at Kew; Wollkoff, on the summit of Koenigstuhl, near Heidelberg (altitude, 550 meters), and Thorpe, at Para, have given the following values of relative intensity of radiation at certain moments when the sun's altitude above the horizon was sensibly the same at all the stations. (See Marie Davy, 1882.)

Relative intensity of radiation for equal altitudes of the sun.

	Latitude.	From sun.	From sky.	Sun + sky.	Sun/sky.
	°				
Manchester.....	N. 53.5	0.043	0.140	0.183	0.81
Kew.....	N. 51.5	.150	.162	.312	0.98
Koenigstuhl.....	N. 49.4	.263	.174	.437	1.51
Paris.....	N. 48.8	.222	.501	.723	0.44
Para.....	S. 00.5	.136	.136	.272	1.00

At Manchester and at Paris the light that comes from the sky is more than double that which comes directly from the sun. When the sun is hidden by clouds, or even partially veiled, it is the radiation from the sky that is of the most importance to agriculture, and in any case this radiation is far from being negligible. The Arago-Davy actinometer (believed to have been invented by Arago before 1844, but improved by Marié-Davy and used at the

observatory of Montsouris ever since 1873) is an apparatus that is intended to determine the total solar plus sky radiation that is needed in agricultural physics. A theory of the action of this instrument was devised by Marié-Davy, but the proper method of calculating its results was first developed with exactness by Ferrel, in *Professional Papers of the Signal Service*, No. XIII (1884), and subsequently in his *Recent Advances in Meteorology* (Annual Report, Chief Signal Officer, p. 373). His formula will be given on page 88.

The Arago-Davy actinometer is composed of two mercurial thermometers with very fine tubes, and having spherical reservoirs of equal dimensions, one colorless and the other covered with lamp-black. In the empty space above the mercury in the thermometer tubes there is a small quantity of hydrogen or other inert gas. The small quantity of gas left in the tubes of these thermometers has no other object than to prevent the mercury from falling in the tube by the force of gravity when the bulb is turned upward toward the sky. Each thermometer is inclosed in a larger glass tube or cylinder, terminated by a spherical enlargement, in the center of which is placed the center of the bulb of the thermometer. This tube and enlargement constitute the inclosure, and it is exhausted of air as perfectly as possible. The immovability of the thermometer, relative to the walls of its inclosure, is assured by a soldering at the upper extremity of the tube and, at the opposite end toward the reservoir, by two rings of cork held by friction between the interior tube and exterior cylinder. These thermometers, with their respective glass inclosures, are turned up with their bulbs toward the sky, and by means of double clamps fixed parallel to two metallic rods, arranged in the form of a V and turned, the one toward the east, the other toward the west. These metallic rods make an angle with each other of  $60^\circ$ —that is to say, of  $30^\circ$  with the vertical—and are fastened to a support of wood or iron 1.20 or 1.30 meters in height above the earth. The support is solidly planted in the ground in an open place, remote from buildings, plants, or any other obstacle capable of intercepting the direct radiation of the sun. The two thermometers, the envelopes of which are exposed near each other, have necessarily the same temperature and mark the same degree as long as they remain in perfect darkness; but hardly does day begin to break than the thermometer with the black bulb marks a higher temperature than that with a plain glass bulb. The difference in temperature of these two thermometers gives the “actinometric degree” for the moment of observation; that is to say, it serves to measure the intensity with which the radiation strikes the two thermometers and is absorbed by the black bulb; consequently, at least approximately, it serves to measure the intensity with which the

radiation strikes the ground and neighboring plants and accumulates therein.

After three years' use of this instrument, Marié-Davy selected the observations made on the days of perfect clearness of the sky, of which there were only nine, since many days that would be called cloudless showed slight traces of haze. For these days the difference between the readings of the black bulb and bright bulb is represented closely by the exponential formula

$$t - t' = 17^{\circ} \times 0.875^e$$

where the exponent *e* represents the thickness of the layer of air through which the sun's rays must pass in order to reach the observer; this thickness, of course, increases as the sun approaches the horizon, being unity for the zenith and 10 for an altitude of 2°, as shown by the following table, which is an abstract of that used by Marié-Davy in his computations:

*Thickness of the layer of air traversed by the solar rays, as computed by Lambert's formula.*

Altitude of sun.	Thick- ness, <i>e</i> .	Altitude of sun.	Thick- ness, <i>e</i> .
°		°	
0	12.69	25	2.80
2	10.20	30	1.96
4	8.28	40	1.54
6	6.83	50	1.30
8	5.75	60	1.15
10	4.92	70	1.06
15	3.58	80	1.02
20	2.80	90	1.00

As the formula of Lambert has been chosen by Marié-Davy for use in connection with his form of actinometer, we have therefore given its results in the preceding table; but as the more accurate formula, as given by Laplace, has been applied to other forms of actinometers, and may even be preferred for the Arago-Davy instrument, I therefore give a table showing the thickness by the formula of Laplace as used by Violle and the value of the intensity (*I*) as given by Violle.

*Thickness of the layer of air traversed by the direct solar rays as computed by Laplace's formula, and the corresponding value of  $I$ , the absolute intensity of direct sunshine in calories per minute per square centimeter which fall normally on any surface through the purest air, as given by Voille.*

Altitude of sun.	Thickness ( $e$ ), La- place formula.	Intensity ( $I$ ) of di- rect sun- shine, Voille.	Altitude of sun.	Thickness ( $e$ ), La- place formula.	Intensity ( $I$ ) of di- rect sun- shine, Voille.
°			°		
0	35.50	0.859	80	1.995	2.275
2	18.90	0.898	85	1.740	2.306
4	12.20	1.293	40	1.555	2.331
6	8.60	1.540	45	1.420	2.349
8	6.85	1.730	50	1.305	2.364
10	5.70	1.868	60	1.155	2.388
15	3.81	2.059	70	1.065	2.395
20	2.90	2.164	80	1.016	2.401
25	2.425	2.229	90	1.000	2.408

Observation shows that no two such Arago-Davy actinometers placed side by side will give exactly the same results; therefore the rule has been adopted of comparing all instruments with the standard kept at Montsouris, and a standardizing factor is thereby obtained by which the observed difference between the bright and black bulb of any pair is to be multiplied in order to reduce it to a common standard.

In addition to the standardizing factor of the preceding paragraph, Marié-Davy has also introduced the conception of an ideal standard actinometer, graduated in such a way that the first factor,  $17^\circ$  in the above-given formula as expressed in centigrade degrees, shall be represented by 100 "actinometric degrees" in his ideal instrument; that is to say, all the differences ( $t-t'$ ) observed with any actinometer, after being multiplied by the standardizing factor, have still to be multiplied by the factor 5.88 in order to convert them into ideal actinometric degrees. For convenience both these factors may be replaced by one, and in this way the instrument and Marié-Davy's methods have been extensively employed in studying the relation between sunshine and crops.

In such study Marié-Davy and his pupils take the "sum of the total number of actinometric degrees" as the datum for comparison with crop reports, instead of the sum of the temperatures of the air observed in the shade, or the sum of the soil temperatures as used by other investigators. If we divide the actinometric degrees given in any case by the factor 5.88 we shall obtain the excess of the black bulb over the bright bulb as originally observed in centigrade degrees. From this we can obtain the true relative quantities of solar radiation by a modification of the method given by Ferrel (pp. 41-50

of his above-quoted work of 1884; on the Temperature of the Atmosphere and the Earth's Surface).

Until such a method has been perfected (see an article by Ferrel in *Am. Jour. Sci.*, May, 1891, 3, Vol. XLI, p. 378) we will for the present quote the actinometric degrees and other figures as ordinarily published by Marié-Davy and others; but the reader must bear in mind that these results from the hypothesis assumed by Marié-Davy that the observed difference between the bright and black bulb is proportional to and therefore a proper measure of the intensity of the radiant heat that falls upon these thermometers; a hypothesis which, as Ferrel has shown, is far from being true. The error of this hypothesis is of such a nature that for a given difference or a given actinometric degree the true intensity of radiation is greater at high temperatures than at low temperatures. Probably the recorded actinometric degrees therefore give a rather low value for the solar and sky radiation during the hottest portions of summer days.

The accompanying table, as published by Marié-Davy, shows the actinometric degrees calculated for the clearest of skies at Paris at noon of each day. They are computed according to the preceding formula, viz,  $A = \text{actinometric degrees} = 100 \times 0.875^{\circ}$ ; in which, as before said, the coefficient, 0.875, represents the penetration or the total heat which penetrates to the observer, both from the sun and the surrounding sky, and includes even that small part that is directly reflected from the surrounding grassy lawn or other surface when the sun is in the zenith; if there were no atmosphere present the total amount received would be 100. It will be less confusing if the reader will consider these so-called "actinometric degrees" as "percentages of what would be received in the absence of the atmosphere."

Columns 5, 6, and 7 of our table give the mean value of the five actinometric percentages observed on the clearest days at 6 a. m., 9 a. m., noon, 3 p. m., and 6 p. m.; in the absence of actual observations these means may be employed in our study, provided we make a proper allowance for the influence of hazy and cloudy skies. It is, however, always desirable that the actual observation of the actinometer should be available, and with it should be associated a simultaneous record of the cloud or haze as given by the sunshine recorder.

*Solar radiation plus sky radiation expressed as actinometric percentages according to Marié-Davy, calculated for skies as clear as at Montsouris and for various latitudes.*

Date.	Noon observation, latitude—			Mean of 5 observations daily, latitude—		
	42° N.	46° N.	50° N.	42° N.	46° N.	50° N.
January 1 .....	73.6	69.9	65.1	38.0	34.6	30.2
January 11 .....	74.5	71.2	66.7	39.0	35.9	31.9
January 21 .....	75.9	72.9	69.0	40.8	37.7	34.2
February 1 .....	77.5	75.1	71.8	42.0	39.9	37.0
February 11 .....	79.1	77.0	74.4	43.5	41.8	39.6
February 21 .....	80.6	78.9	76.7	45.0	43.6	41.9
March 1 .....	81.6	80.1	78.4	46.2	44.9	43.7
March 11 .....	82.8	81.6	80.1	49.6	48.6	47.5
March 21 .....	83.8	82.8	81.6	55.7	55.0	54.2
April 1 .....	84.7	83.8	82.9	60.7	60.6	60.2
April 11 .....	85.3	84.6	83.8	65.0	65.1	65.1
April 21 .....	85.8	85.2	84.6	68.4	68.7	68.9
May 1 .....	86.2	85.7	85.0	71.0	71.5	71.8
May 11 .....	86.5	86.0	85.5	73.0	73.4	73.8
May 21 .....	86.7	86.3	85.8	74.3	74.9	75.3
June 1 .....	86.8	86.5	86.0	75.3	75.9	76.3
June 11 .....	86.9	86.5	86.2	75.9	76.3	76.8
June 21 .....	87.0	86.6	86.2	76.0	76.6	77.0
July 1 .....	86.9	86.5	86.2	75.8	76.3	76.8
July 11 .....	86.8	86.5	86.0	75.3	75.9	76.3
July 21 .....	86.7	86.3	85.8	74.4	75.0	75.4
August 1 .....	86.5	86.0	85.5	73.0	73.5	73.8
August 11 .....	86.2	85.7	85.1	71.0	71.5	71.9
August 21 .....	85.8	85.2	84.5	68.4	68.8	69.0
September 1 .....	85.3	84.5	83.7	64.7	64.8	64.8
September 11 .....	84.6	83.8	82.8	60.5	60.2	59.9
September 21 .....	83.8	82.8	81.6	55.9	55.3	54.5
October 1 .....	82.9	81.7	80.2	49.4	48.5	47.5
October 11 .....	81.7	80.3	78.5	46.1	45.0	43.6
October 21 .....	80.4	78.7	76.4	44.8	43.4	41.6
November 1 .....	78.8	76.6	73.9	43.3	41.5	39.1
November 11 .....	77.2	74.7	71.4	41.3	39.0	36.0
November 21 .....	75.7	72.7	68.8	40.2	37.5	34.0
December 1 .....	74.4	71.0	66.5	38.8	35.7	31.7
December 11 .....	73.5	69.8	65.0	37.9	34.5	30.1
December 21 .....	73.2	69.4	64.4	37.6	34.1	29.5
January 1 .....	73.6	69.9	65.1	38.0	34.6	30.2

#### THEORETICAL FORMULÆ FOR ACTINOMETER.

In reply to some criticisms of Violle, Marié-Davy (1880, p. 245) gives the only statement that I have seen of his theory or explanation of the working of his conjugate thermometers. It is about as follows: Let—

$a$  be the absorbing power of the bright bulb.

$l$  the absorbing power of the black bulb.

$c$  a numerical coefficient for converting degrees of temperature into a quantity of heat.

$q$  the quantity of radiation or heat falling per minute on the black bulb and also on the bright bulb.

$a q$  the quantity of radiation absorbed by the bright bulb.

$l q$  the quantity of radiation absorbed by the black bulb.

$e$  the emissive power of the black bulb.

$e'$  the emissive power of the bright bulb.

$t$  and  $t'$  the temperatures of the black and bright bulbs, respectively, when they come to the stationary temperature that indicates equilibrium between absorption and emission.

$T$  the temperature of the glass envelopes within which the thermometers are inclosed in a space that is an approximate vacuum.

On the assumption of the Newtonian law of radiation, viz, that the quantity of heat emitted is proportional to the excess of temperature, we have the following relations:

$$\begin{aligned} q &= c e (t - T) \\ a q &= c e' (t' - T) \end{aligned}$$

From these expressions we can, by elimination of  $T$ , find the following expression for  $q$ —that is to say, the quantity of solar radiation per unit of time that is at that moment falling on the two thermometers, at least in so far as this radiation is capable of being transformed into heat by absorption into the bulbs of the thermometers:

$$q = \frac{c e e'}{e' - a e} (t - t')$$

Marié-Davy, in the absence of exact knowledge of these coefficients  $a$ ,  $c$ ,  $e$ ,  $e'$ , prefers to attempt to determine only relative measures of the intensity of radiation. He therefore assumes that the expression

$\frac{c e e'}{e' - a e}$  is equal to 5.88 units, and the values for  $q$  thus obtained he

calls actinometric degrees, since on the very clearest days in Paris they accord well with the assumption that the so-called solar constant of radiation is 100 actinometric degrees, and that the coefficient of transmission of sunshine through the atmosphere is 0.875.

Ferrel (1884), in his memoir on the temperature of the atmosphere (p. 41), has improved upon Marié-Davy's theory, in that he has applied to the conjugate thermometers the law of radiation, established by Dulong and Petit in 1817, which is applicable to a much larger range of temperatures than the Newtonian law adopted by Marié-Davy. Ferrel's formula may be written:

$$q = 4.584 k m^{t'} (m^{t-t'} - 1)$$

where the notation is the same as before, except that  $m$  is the number 1.0077, as determined by Dulong and Petit and  $k$  is a factor that varies with the quality of the bright bulb, whose absolute value is



usually greater than  $l$ , but whose relative value may by preference be determined by referring each pair of conjugate thermometers to an adopted standard pair. Ferrel's formula is especially devised for thermometers having spherical bulbs, measures made by it at high and low temperatures give results that are comparable with each other; for absolute results the numerical coefficients may need some modification, but as it stands it gives the values of  $q$  approximately in calories per minute per square centimeter.

Omitting for the present the factor  $k$  in Ferrel's formula, which must be specially applied for each thermometer, we have the values of  $q$  in calories as given in the following table (see Ferrel, p. 37), which also presents the corresponding values given by the formula of Marié-Davy in actinometric degrees. In a critical study of observations reduced by these two methods we have to recall that Marié-Davy's actinometric degrees are really fractions of a calorie, or units of heat so small that 100 of them are equivalent to the absolute radiation of the sun received at the outside of an atmosphere whose coefficient of transmission is 0.875; whereas Ferrel's calories have been adopted without predicating anything as to the solar radiation or atmospheric absorption, concerning which his observations show that the solar radiation constant is between 2 and 2.25 calories per minute per square centimeter and the atmospheric coefficient of transmission to be used with the conjugate bulbs is 0.72.

*Solar radiation deduced from observations with the conjugate thermometers.*

$t - t'$	Marié-Davy, actinometric degrees.	Ferrel, calories per minute per square centimeter for the respective bright-bulb temperatures.								
		-10°	-5°	0°	+5°	+10°	+15°	+20°	+25°	+30°
° C.										
5.....	29.4	0.166	0.172	0.179	0.186	0.194	0.201	0.209	0.217	0.226
10.....	58.8	.339	.352	.366	.380	.395	.410	.426	.443	.460
15.....	88.2	.518	.538	.559	.581	.604	.627	.652	.678	.704
20.....	117.6	.705	.732	.761	.791	.822	.854	.887	.922	.958
25.....	147.0	.898	.933	.969	1.007	1.047	1.087	1.131	1.175	1.220
30.....	176.4	1.099	1.142	1.187	1.234	1.282	1.332	1.385	1.438	1.495
35.....	205.8	1.309	1.360	1.413	1.469	1.526	1.585	1.647	1.712	1.778
40.....	235.2	1.525	1.585	1.646	1.711	1.778	1.848	1.920	1.995	2.073
45.....	264.6	1.750	1.820	1.891	1.964	2.042	2.121	2.204	2.291	2.380

#### INTENSITY AND DURATION OF SUNSHINE AT MONTSOURIS.

In order to have at hand data that will enable one to approximately infer some of the relations between the temperature of the air and of the soil and of the solar radiation, one may consult the tables for the observations at Montsouris, given by Marié-Davy in his *Annuaire* for 1887.

As those who can not make use of the actinometric degrees deduced by Marié-Davy from his observations of his conjugate bulbs will necessarily have to use either the simple observations of clear sky and cloudy sky, as given by the sunshine recorder, or the equivalent personal observations of the clouds, I give the following tables, which show how nearly parallel these two phenomena may be. Evidently in our study of the influence of insolation on crops in America from year to year we may use the sunshine recorder or the ratio between the actual and the maximum possible duration of sunshine without much error, at least in the growing season.

*Mean of five daily actinometric observations at Montsouris, expressed in Marié-Davy's actinometric degrees or percentages of maximum possible intensity.*

Month.	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.
April.....	44.1	40.1	36.3	35.4	28.6	38.9	33.0	39.7	36.8	34.5	34.1
May.....	47.7	45.8	38.7	41.5	40.6	50.3	48.9	47.4	45.9	46.3	40.3
June.....	46.0	48.8	54.5	47.7	45.1	41.2	53.3	47.0	45.3	43.2	46.1
July.....	47.3	52.1	48.6	50.6	41.2	50.0	52.0	46.6	42.2	43.4	49.4
August.....	39.9	42.0	43.2	37.8	42.3	39.1	40.3	34.0	39.0	36.2	36.4
September.....	35.7	30.9	31.4	30.9	32.7	30.2	28.3	27.1	30.5	30.8	24.1
Average.....	43.5	43.5	42.1	40.7	38.0	41.6	42.7	40.3	39.9	39.1	38.4

*Mean of five daily observations of the cloudiness at Montsouris expressed as ratio of the actual duration of sunshine to the maximum possible duration.*

Month.	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.
April.....	0.66	0.60	0.54	0.53	0.43	0.58	0.49	0.60	0.55	0.52	0.51
May.....	.64	.62	.52	.56	.55	.68	.66	.64	.62	.62	.54
June.....	.60	.64	.71	.62	.59	.54	.70	.61	.59	.56	.60
July.....	.63	.69	.64	.67	.55	.66	.69	.62	.56	.57	.55
August.....	.57	.60	.62	.54	.61	.56	.58	.50	.56	.52	.52
September.....	.62	.54	.55	.54	.67	.53	.49	.47	.53	.54	.42
Average.....	.62	.62	.60	.58	.55	.59	.60	.57	.57	.55	.52

#### **RELATIVE TOTAL HEAT RECEIVED FROM SUN AND SKY DURING ANY DAY, BY HORIZONTAL SURFACES.**

A more accurate way of considering the amount of insolation at any locality is to compute the total radiation (expressed by its equivalent heat in calories) received by a horizontal surface in the natural daytime of that day and latitude, taking account of the absorption by the atmosphere. (See *Annales Agronomique*, 1878, IV, pp. 270-296, or *Ann. Report Chief Signal Officer for 1881*, pp. 1200-1216.) This has been done by Aymonnet by a graphic method. He assumes that if the sun were in the zenith then the unit of horizontal earth's surface would, because of atmospheric absorption, receive only 0.75 of

the heat that it would receive if it were outside the atmosphere. Of the remaining 25 per cent one-half reaches this horizontal unit by way of the diffuse reflection from the sky, so that with the sun in the zenith the unit receives 0.875 of the original solar heat. For a point on the equator during twelve hours this would amount to  $0.875 \times 12 \times 60 \times 60$  of the total possible if the sun were in the zenith. Using this as a basal datum, Aymonnet obtains the relative numbers given in the following table or the ratio of the heat actually received during one day to that which would have been received if the sun had stood for twelve hours in the zenith. Thus on June 20, at latitude  $30^\circ$ , the horizontal unit receives 0.347 of that corresponding to the ideal sun in the zenith all day, while at the north pole on the same day the horizontal unit received during twenty-four hours 0.328 of what it would had the sun stood in the zenith for twelve hours. In fact the amount of heat received by horizontal surfaces is nearly uniform for all latitudes for the days June 15–July 28. These relative numbers or ratios may be turned into absolute calories by multiplying them by the so-called “solar constant,” whose value is probably between two and three calories per minute per square centimeter.

*Relative quantities of total heat received on specified days from the sun and sky at different latitudes by a unit surface of horizontal ground during one cloudless day, allowing for the absorption and diffuse reflection of ordinary clear air, as computed by Aymonnet.*

Dates, 1874.	Declination of sun, north.	Latitude—						
		0°.	10°.	30°.	50°.	70°.	80°.	90°.
March 20 .....	0 07	0.301	0.295	0.255	0.175	0.075	0.029	0.000
March 28 .....	3 02	.288	.297	.268	.190	.098	.049	.017
April 7 .....	6 52	.295	.303	.284	.215	.127	.082	.058
April 15 .....	9 48	.292	.306	.296	.235	.157	.115	.100
April 25 .....	13 14	.288	.307	.310	.261	.191	.159	.151
May 5 .....	16 17	.284	.305	.322	.281	.226	.207	.205
May 15 .....	18 54	.279	.304	.331	.298	.255	.249	.250
May 25 .....	20 58	.274	.304	.337	.313	.283	.280	.286
June 5 .....	22 34	.272	.303	.342	.324	.304	.312	.318
June 15 .....	23 20	.268	.302	.346	.329	.314	.328	.326
June 19 to 23 .....	23 27	.267	.301	.347	.330	.315	.325	.328
July 7 .....	22 36	.272	.303	.342	.324	.304	.312	.314
July 19 .....	20 51	.274	.304	.337	.313	.282	.279	.284
July 28 .....	18 50	.279	.304	.331	.298	.255	.249	.251
August 7 .....	16 25	.284	.305	.322	.281	.226	.209	.207
August 18 .....	13 06	.288	.307	.310	.261	.191	.159	.152
August 25 .....	10 45	.290	.307	.301	.242	.164	.128	.115
September 5 .....	6 48	.295	.303	.284	.215	.127	.082	.058
September 15 .....	3 00	.298	.297	.268	.190	.098	.049	.017
September 23 .....	0 06	.301	.295	.255	.175	.075	.029	.000

**RELATIVE TOTAL HEAT RECEIVED DURING CERTAIN MONTHS.**

By adding the amount for each day of any month in the following table we get the relative numbers for the total amount of heat received direct from the sun at various latitudes during certain months by a unit of horizontal surface under a clear sky, and after absorption by ordinary clear air, plus the amount received from the diffuse sky light or the atmospheric reflection, all expressed in terms of the amount that unit surface would receive if the sun were constantly in the zenith during twelve hours. The coefficient of transmission through one atmosphere for zenithal sun is, as before, 0.75, and the added skylight is 0.125, to accord with the Arago-Davy conjugate thermometers, since these are affected by the sum of the heat received by their surfaces from the sun and from the atmospheric particles in the visible celestial vault.

*Relative quantities of total heat received monthly at different latitudes in the northern hemisphere.*

Month.	0.	10.	30.	50.	70.	80.	90.
March 20 to 31 .....	3.7	3.7	3.8	2.8	1.1	0.6	0.2
April.....	10.0	10.6	10.1	8.0	5.4	3.9	3.4
May.....	9.8	10.7	11.7	10.5	9.0	8.6	8.7
June .....	9.2	10.4	11.9	11.8	10.7	11.0	11.1
July.....	9.7	10.7	12.1	11.3	10.8	10.1	10.2
August .....	10.1	10.7	10.9	9.2	6.8	5.9	5.8
September 1 to 23.....	7.7	7.8	7.1	5.3	2.7	1.5	0.9
Total.....	60.2	64.6	67.1	57.8	46.0	41.6	40.8

**PHOTO-CHEMICAL INTENSITY OF SUNSHINE.**

Bunsen and Roscoe, in a series of memoirs published in the Philosophical Transactions, London, 1857, 1859, and 1863, entitled, "Photo-chemical researches," discussed the methods of measuring the chemical action of light by help of photographic tints, and endeavored to improve upon the methods of Herschel, Jordan, Claudet, and Hankel. They adopted as a standard unit for measurement that intensity of the light which in one second of time produces the standard tint of blackness upon the standard paper. Their methods are too laborious for the ordinary meteorological observer, but have furnished some important data as to the chemical activity of diffuse sunlight and of total daylight.

In his memoir of 1864, Roscoe states that he and Bunsen had developed a method of determining the chemical intensity of both direct sunlight and diffuse sunlight, or the total daylight, that is, based upon the law that the intensity of the light multiplied by the duration of exposure of chloride of silver paper of uniform sensitiveness gives a series of numbers proportional to the shades of tints,

so that light of the intensity 50, acting during time  $t$ , produces the same blackening effect as light of intensity  $t$  acting during the time 50. According to this method the chemical action of the total daylight was determined for Manchester, England, many times a day during 1864, and the total daily chemical intensity has been computed for the year August, 1863, to September, 1864. Very large changes in chemical intensity occur when the sky is cloudless and unchanged as far as the eye can perceive. The total intensity for an apparently cloudless day varies from 3.3 for December 21, 1863, to 119, June 22, 1864. This last number, compared with the figure 50.9 for June 20, and 26.6 for June 28, shows the enormous variations that take place in the chemical rays that reach the observer at Manchester on cloudless days. This variation is undoubtedly due in part to smoke and moisture, but possibly other unknown influences are also at work.

In 1867 H. E. Roscoe communicated to the Royal Society the results of work done by his method at Kew, England, in 1865, 1866, and 1867; at Heidelberg, 1862 and 1863, and at Para, Brazil, 1866. The general results are that the chemical intensity attains its maximum at noon and not, like the temperature, at some time after noon. Everywhere the intensity increases from hour to hour with the altitude of the sun, and is very closely proportional to it even when the sky is partially clouded, but of course the rate of increase varies with the season, the amount of cloud, and the degree of atmospheric opalescence. The total chemical intensity for each month, as determined from numerous observations, is as follows for Kew:

*Total photochemical intensity of direct and diffuse light (Roscoe).*

Month.	1865.	1866.	1867.	Month.	1865.	1866.	1867.
January.....		15	13	July.....	114	107	
February.....		24	22	August.....	89	94	
March.....		34	31	September.....	108	70	
April.....	98	52		October.....	23	29	
May.....	118	79		November.....	18	16	
June.....	82	92		December.....	(8)	(14)	

Roscoe compares these figures with the cloudiness, and finds that the ratio between cloudiness, expressed on a scale of 10, and the chemical intensity is as 1 to 5 in some months and as 1 to  $\frac{1}{2}$  in others. A similar irregularity of ratio is found when he considers the absolute moisture in the atmosphere; whence he concludes that the variations in chemical intensity, as between the spring and autumn, are not perfectly explained by either of these factors. He finds the high autumnal and low vernal intensity fairly well explained as due to the transparency or opalescence produced by finely divided solid particles or dust.

Passing from Kew to Para, it appears that the chemical action of total daylight during the month of April, 1866, at Para was 6.6 times as great as at Kew.

In order to obtain data for a clearer atmosphere, Roscoe and Thorpe conducted observations in 1867 near Lisbon; Portugal, and published their results in a memoir of 1870, where they have given the relation between the sun's altitude and the chemical intensity. The intensity is the same for hours that are equidistant from apparent noon. The relative intensity of direct sunlight, reflected sky light, and total insolation is shown for different altitudes at Lisbon by the following table:

*Intensity of insolation at Lisbon for clear skies.*

Mean altitude of sun.	Number of observations.	Observed chemical intensity.		
		Sun.	Sky.	Total.
°				
9.85	15	0.000	0.068	0.068
19.68	18	.023	.062	.085
31.23	22	.052	.100	.152
42.22	22	.100	.115	.215
53.15	19	.136	.126	.262
61.13	24	.195	.132	.327
64.23	11	.221	.138	.359

In general, the total intensity is directly proportional to the number of degrees of altitude. For altitudes between  $18^{\circ}$  and  $35^{\circ}$  the intensity on a plane perpendicular to the incident rays is about the same as the intensity of total sky light on a horizontal plane. The intensity of direct sunlight on a horizontal plane is equal to the intensity of total sky light on a horizontal plane when the sun's altitude is about  $45^{\circ}$ . At all altitudes of the sun below  $21^{\circ}$  the chemical action of diffuse daylight exceeds that of direct sunlight.

In their memoir of 1871 Roscoe and Thorpe determined the amount of chemical action for total sky light of a cloudy sky during totality of the solar eclipse, and found it much less than 0.003, and therefore not measurable. They found the total chemical action of the direct sunlight to be strictly proportional to the visible area of the portion of the solar disk up to a certain point in the obscuration, after which the influence of sky light is inappreciable. For altitudes below  $50^{\circ}$  at Catania, Sicily, as elsewhere, the amount of chemical action effected by diffuse daylight on a horizontal surface is greater than that exerted by the direct sunlight. At altitudes less than  $10^{\circ}$  direct sunlight is almost completely robbed of its chemically active rays.



### PHOTOGRAPHIC INTENSITY OF SUNSHINE.

A photographic method of determining the brightness of sunshine or sky light is very desirable as supplementing the thermometric methods. It is as erroneous to assume that all radiation that falls upon a black-bulb thermometer is absorbed by it and converted into heat and measured by the expansion of the mercury as it is to assume that all the radiation that falls on a photographic film is absorbed by it and is represented by the chemical changes that take place in the film. Equally erroneous would it be to assume that all the radiation that enters the eye is represented by the impression of brightness conveyed by the retina to the brain. In order to measure in absolute units the total energy radiated from the sun, we need a proper summation of the thermal, visual, and photographic work done by the radiation. If we wish to determine only the intensity of that part of the radiation that does the work in which agriculture is chiefly interested we should consider only the heating effects of the radiation and the special chemical effects manifested in the action of sunlight upon chlorophyll.

The action of the sunlight upon the chlorides and bromides of silver, as in ordinary photographic processes, may not be an exact measure of its action upon the leaves of plants. Some other chemicals may be more appropriate for use at agricultural experiment stations, but the photographic methods perfected by Profs. H. W. Vogel and L. Weber are worthy of trial as a first step in the right direction. These processes give us the relative intensity of the radiations that belong to the blue end of the spectrum, with only a small admixture of the influence of green and yellow rays.

During the year 1890, as the result of a numerous series of observations at Kiel, Prof. L. Weber found that the reddish light of the spectrum on dark winter days has only about 500 times greater intensity than the quantity of light from a normal candle at a distance of 1 meter, when measured by their relative effects on a photographic plate, while at the same time the photographic intensity of the green light of the spectrum was four times as much. On bright summer days the intensity of the red light was 50,000 times that of the candle at 1 meter, while the intensity of the green light was about 200,000, or about 4 times as much in summer as in winter. The intensity of the blue light in the solar spectrum was about 25 times that of the red light, which ratio varied a little with the kind and amount of cloud. In all this photographic work a very sensitive silver bromide paper was used; so that these results, strictly speaking, relate only to the variations in the intensity of those special rays that affect this chemical. But these variations will be nearly parallel to the diurnal and annual variations of the rays that affect the growth of plants.



Further details of Weber's results are given in the German periodical, *Photographische Mittheilungen*, edited by Professor Vogel, at Berlin.

It is worth while to call attention to the fact that during the long twilights of northern latitudes in midsummer plants receive an appreciable quantity of the blue radiations from the sky, while receiving little or nothing of the red, or heat, rays.

#### MARCHAND'S SELF-REGISTERING CHEMICAL ACTINOMETER.

A convenient form of registering actinometer is that devised by Marchand (1875), which he at first called "photantitupimeter," but which name he afterwards contracted and modified to "phantupimeter." This consists of a vertical graduated tube, closed at the upper end, into which there can escape and be measured the carbonic acid gas given off by the decomposition of a mixture of solutions of perchloride of iron and oxalic acid. By the action of sunshine on this mixture, carbonic acid gas is slowly disengaged, and by its accumulation in the measuring tube gives us apparently a means of determining the sum total of the influences of the sun during any period. This apparatus was diligently employed for many years by Marchand at Fecamp, near Havre, and has afforded him many interesting results.

#### COMPARISON OF MARCHAND'S AND MARIE DAVY'S RESULTS.

Radau (1877), in his work on Light and Climate, states that the results given by different methods of measurement of sunshine appear to differ largely among themselves, but yet there is a certain similarity in the figures. The accompanying table shows the results of observations by Marchand's chemical method and by Marié-Davy's thermometric method, or conjugate thermometers, which latter, on account of its convenience, has been widely adopted.

Month.	T e m p e r a t u r e ( ° C )	Month.	Total daily chemical effect, in cubic cen- timeters, of car- bonic acid (Fecamp, 1860-1872)	Mean daily record of actinomet- ric de- grees (Mont- souria, 1872-1876)	
January .....	3.98	15.6	August .....	18.02	41.2
February .....	6.44	26.0	September .....	18.06	31.8
March .....	14.10	37.5	October .....	8.86	20.1
April .....	19.46	48.2	November .....	2.89	12.5
May .....	21.04	50.6	December .....	1.60	2.4
June .....	21.41		Annual average .....	11.08	29.3
July .....					

If the atmosphere were not so very different at these two localities, we could have hoped to use the monthly ratios of these numbers for reducing similar series elsewhere to a common standard.

### VIOLLE'S CONJUGATE BULBS.

The refined methods for measuring solar radiation adopted by Violle (1879) in his absolute actinometry can hardly be utilized in agricultural investigations owing to the labor of using the apparatus. But the continuous register obtained by him by means of thermoelectric apparatus is an important improvement in the methods available for comparing climates. On the other hand, Violle has suggested a modification of the conjugate thermometers which he calls his "conjugate bulbs," which is worthy of consideration, although far from being as sensitive as Marié-Davy's apparatus. These bulbs are made of thin copper, one of them blackened and the other gilded on the outside; the interiors are blackened, and the thermometer bulbs within them are also blackened. This apparatus has an apparent advantage over Marié-Davy's, in that the sunlight is not required to pass through glass before striking the thermometer. It would appear likely that with smaller bulbs (Violle uses 1 decimeter in diameter) and with more sensitive thermometers Violle's method might give better results and be worthy of recommendation to agricultural investigators. The results given by his apparatus have need to be reduced by some method based on the considerations indicated by Ferrel (1891).

### BELLANT'S RADIOMETER OR VAPORIZATION ACTINOMETER.

Among the many devices invented for the purpose of obtaining, at least approximately, the sum total of the effect of sunshine received during any day by a given plant is one that has been used for a few years at the Montsouris Observatory, and is a modification of an apparatus originally devised by the Italian physicist, Angelo Bellani, which is thus described by Descroix (p. 128, *Annuaire de Montsouris*, 1887; see also the *Annuaire* for 1888, p. 206, where it is called the *lucimeter*, although it does not measure light properly so called).

The vaporization actinometer or the Bellani radiometer as modified at Montsouris consists of a bulb of blue glass A of about 60 mm. in diameter, inclosed within a larger bulb B of colorless glass. The space between the two bulbs is a vacuum. A is two-thirds filled with a volatile liquid and the space above it contains only its vapor, which passes through a curved tube down into a large bulb C, of clear glass, and thence down into the vertical tube D, which is graduated, and where the condensing liquid can be measured.

Under the action of the radiation from the sun and the sky the blue bulb A is warmed more than the bulb B; a distillation takes place from A and the condensed liquid is collected in the graduated tube D, where its volume is measured. This condensation in D is a source of heat, while the vaporization in A is a source of cold. The heat given off by condensation must equal that consumed in evaporation, and is drawn off from the apparatus by the action of the cool

wind blowing past C and the graduated stem D, which are shaded from the sunshine, or which may be kept immersed in melting ice, although this is not done at Montsouris. In order that the record of liquid condensed in C and D may be proportional to the heat received by A it is necessary that the volume of condensed liquid be independent of the temperature of the air and of the volume of liquid remaining in the bulb A, and be controlled only by the excess of radiant heat received by A over that received by C and D.

The comparisons that have been made at Montsouris between this Bellani radiometer and the Marié-Davy actinometer, or the so-called conjugate thermometers, show that the Bellani apparatus does not perfectly satisfy the theoretical conditions, but as it is extremely sensitive, since it distills 16 or 17 centimeters daily, and as the apparatus is not costly, Descroix has devised a formula for reducing its results to a standard. The following table gives the results of actual observations, showing the average results for the middle portion of perfectly clear days at Montsouris, near Paris, monthly during the growing seasons of 1885 and 1886. The column N shows the number of clear days; V, the volume of alcohol distilled over from 9 a. m. to 3 p. m. on these days in the Bellani apparatus; t, the average temperature of the air in the shade;  $T_1$ , the average temperature of the black bulb thermometer in vacuum in the sunshine;  $T_2$ , average temperature of the bright-bulb thermometer in vacuum in the sunshine;  $T_1 - T_2$  is the average difference of these conjugate thermometers at midday; R, total illumination from the sky at midday, expressed in Marié-Davy's actinometric percentages or degrees.

*Comparison of actinometric results for perfectly clear days at Montsouris, near Paris, by the Bellani radiometer and by the Arago-Davy actinometer.*

Month.	N.	Bellani.		Arago-Davy at noon.			
		V.	t.	T <sub>1</sub> .	T <sub>2</sub> .	T <sub>1</sub> -T <sub>2</sub> .	R.
1885.		ccm.	°C.	°C.	°C.	°C.	
March .....	6	9.6	5.9	25.9	15.0	10.9	73.9
April .....	6	10.4	18.4	38.5	27.5	11.0	70.2
May .....	2	10.2	22.6	44.2	32.9	11.3	67.1
June .....	10	10.7	22.8	45.6	33.7	11.9	71.5
July .....	15	11.6	24.7	46.2	34.4	11.8	73.9
August .....	8	10.7	20.0	39.9	29.2	10.7	73.2
September .....	8	11.0	23.4	43.0	32.1	10.9	73.2
October .....	2	7.2	12.1	29.5	4.1	8.4	72.0
1886.							
March .....	8	11.9	1.6	22.5	11.0	11.5	77.2
April .....	7	12.3	17.6	36.7	26.8	9.9	74.1
May .....	9	12.9	15.6	38.7	25.9	12.4	76.6
June .....	2	12.1	19.5	42.7	30.2	10.2	75.2
July .....	10	12.5	23.2	44.4	32.9	11.5	72.0
August .....	7	12.1	22.9	41.8	31.3	10.5	68.6
September .....	11	11.7	21.0	38.8	28.9	9.9	69.2
October .....	4	10.1	19.3	35.9	26.6	9.3	71.2

Notwithstanding the simplicity of Bellani's apparatus and the ingenuity of the idea embodied therein it is evident that it needs an important modification, viz, the evaporation and condensation should

be absolutely independent of the temperature of the air and the velocity of the wind, as well as of the quantity of liquid in the bulb A, and should depend wholly on the heat received from the sun and sky. In its present form it can not be recommended as a simple means of measuring the daily sum total of radiation from the sun and sky. A second and improved form of Bellani's apparatus has been brought out under the title "Vaporization lucimeter" (see Marié-Davy, *Annuaire*, 1888, p. 207), but further improvements are necessary, especially the maintenance of a uniform constant temperature in the condensation bulb and tube, as, for instance, by immersing both in a bath at melting point of ice.

#### **ARAGO'S CYANOMETER AND DESAINS' THERMO-ELECTRIC ACTINOMETER.**

Other methods of observing the condition of the sky and solar radiation have been devised by physicists. Thus the cyanometer of Arago, especially in the modified form made by Dubosc, of Paris, or the thermo-electric actinometer of Desains (both of which are in occasional use at Montsouris) give useful indications. The cyanometer gives the blueness of the sky, which is largely dependent on the number and size of the particles of moisture, while the actinometer gives the quantity of heat that penetrates directly from the sun through this moist air to the ground. These instruments are complementary to each other, but can only give good results in the hands of those accustomed to the use of delicate apparatus. They serve as checks upon the records of the Arago-Davy actinometer, which latter has been made by Richard in such form as to keep a continuous register. Thus during the years 1879-1886 the Arago-Davy instruments, both in France and in India, showed a steady, progressive diminution in the intensity of the solar radiation received at the ground, followed, however, by a recovery, subsequently, which is not likely to have been due to any instrumental peculiarity. This peculiar fluctuation may have had its cause either in the sun or in the earth's atmosphere.\*

#### **DURATION OF SUNSHINE.**

Those who can not undertake the labor of observing the heating or chemical effects of the solar radiation can easily keep a photographic register of the number of hours of sunshine, as in the apparatus devised by Jordan, of England, and modified by Marvin for use at Signal Service stations, or can keep a record of the hours of full hot sunshine, as in the Campbell, or Campbell-Stokes, sunshine recorder used in Canada. The Marvin photographic sunshine reg-

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\* This paragraph, written in 1891, is of special interest in connection with the general interest in the subject awakened in 1903 by the observations of Kimball, Dufour, and Abbott.

ister has been established at 20 Signal Service stations, the list of which is given in our tabular data. This tabular matter is omitted from this present edition, and these records will undoubtedly be so fully published as to be available to the student. Such photographic sunshine records are complementary to the ordinary record of cloudiness and of personal observations of the area apparently covered by clouds. But as the photographic register, strictly speaking, records only the cloudy condition of the sky in the immediate location of the disc of the sun, while personal estimates of the amount of cloudiness refer to the whole sky (above an altitude of  $15^{\circ}$ ,  $30^{\circ}$ , or  $60^{\circ}$ , according to the various rules adopted by observers), therefore there is room for quite a discrepancy between the personal and the photographic record, and it is still a question as to which is more appropriate for agricultural study.<sup>a</sup>

In order to know the cloudiness, sunshine, and rainfall at a few stations representative of the district in which cereals are grown in America, I have added to the stations in the United States, which will be published by the Signal Service, the following table for 1887 compiled for Winnipeg, Manitoba (lat. N.  $49^{\circ} 40'$ , long. W.  $97^{\circ} 10'$ ), from the data published by Carpmael (1890), from whose report other records may be obtained.

*Sunshine and climate of Winnipeg.*

Month (1887).	Rainfall.		Average cloudiness.	Average duration of sunshine per hour in percentage of total possible.							
	Inches.	Number of days.		5 a. m.	6 a. m.	7 a. m.	8 a. m.	9 a. m.	10 a. m.	11 a. m.	12 m.
			P. ct.								
January .....	0.00	0	40				2	40	54	71	70
February .....	T.	1	42			11	30	58	61	67	70
March .....	T.	1	50			12	48	55	55	54	54
April .....	0.25	4	51		15	32	44	57	64	65	70
May .....	3.01	13	54	8	29	53	53	55	59	65	59
June .....	2.94	12	50	30	45	57	57	60	62	78	74
July .....	1.98	13	54	20	55	63	67	68	66	74	78
August .....	1.49	15	51		15	42	59	67	73	72	71
September .....	1.77	12	43		8	17	57	71	71	68	71
October .....	0.25	4	57				28	48	44	48	52
November .....	T.	1	50				5	29	48	60	51
December .....	T.	1	65					11	26	42	48

<sup>a</sup> Elaborate comparisons of these records were published from month to month in the Monthly Weather Review during 1892-1897.

*Sunshine and climate of Winnipeg—Continued.*

Month (1887).	Average duration of sunshine per hour in percentage of total possible.								Temperature.		
	1 p. m.	2 p. m.	3 p. m.	4 p. m.	5 p. m.	6 p. m.	7 p. m.	8 p. m.	Maxi- mum.	Mini- mum.	Mean.
									°F.	°F.	°F.
January .....	68	54	60	31	0	-----	-----	-----	28.2	-42.7	-14.5
February .....	70	66	64	49	20	1	-----	-----	24.8	-38.7	- 8.0
March .....	55	56	57	57	48	8	0	-----	43.0	-36.5	11.7
April .....	68	62	64	59	49	35	13	-----	74.8	- 9.0	37.3
May .....	56	57	41	47	49	53	41	5	90.6	29.0	57.2
June .....	84	73	69	59	67	63	48	18	88.0	33.3	64.6
July .....	75	76	72	64	71	68	59	29	93.2	39.0	66.5
August .....	70	70	71	71	60	58	30	5	88.0	33.3	61.0
September .....	76	75	72	70	38	10	5	-----	83.8	23.2	53.8
October .....	60	62	57	44	18	-----	-----	-----	64.0	- 2.8	32.4
November .....	50	49	48	51	14	-----	-----	-----	58.6	-31.4	17.4
December .....	54	55	44	23	-----	-----	-----	-----	38.0	-41.7	- 0.8

In the above table the records of sunshine are, of course, given by the self-registering method and relate to duration of visibility of sun at the station, while the cloudiness is the average of the observer's estimates of area of sky covered.

**TOTAL POSSIBLE DURATION OF SUNSHINE BY DECADES.**

Tables showing the times of sunrise and sunset, or the resulting length of the day, are given in publications accessible to American readers, as follows: Meech, 1855, pages 57, 58, calculated especially for the year 1853; Schott, 1876, pages 117-119, computed for an average year and for the actual sunrise and sunset and for each degree of latitude; the Smithsonian Meteorological and Physical Tables, fourth edition, 1884, give a very convenient table on pages 711-720, by Prof. W. Libbey, computed with the declinations for Greenwich mean noon for 1862; elaborate general tables are given in the International Meteorological Tables, Paris, 1890, but they are not so convenient for our use as the Smithsonian tables or those of Schott.

By means of these tables of sunrise and sunset I have computed the accompanying table, showing the sum total of the possible sunshine expressed in hours from the beginning of January up to any date in a common year or a leap year.<sup>a</sup> From this table has been made up the column of maximum sunshine in the tables of meteorological results for 1879 at twenty stations in the United States as given in Section II for comparison with the crops of that year, as reported in the United States census for 1880.<sup>b</sup> In the absence of any other data

<sup>a</sup> The annual sums for December 31 in the table are about one-third to one-half per cent smaller than the figures given in the Weather Bureau table of 1905.

<sup>b</sup> All these manuscript statistical tables are omitted in the present edition.

one may multiply the duration of sunshine by the percentage of observed clearness and obtain the duration of sunshine for a special station. But this will give us a value that is greater or less than the value of the true intensity of sunshine according as the cloudiness occurs mostly in the morning and evening or in the midday hours. The only method for obtaining a satisfactory value of the intensity of radiation as coming direct from the sun or as reflected from the sky, the clouds, and the earth, is to maintain a self-registering actinometer or, in place of that, frequent daily observations.

In these tables I have adopted the division of each month into three parts, as done by Libbey and occasionally used by meteorologists, but the system of pentades, used by Dove, is often preferable; however, this present system is convenient for monthly summations, and is also used in the climatic table of Section II.<sup>a</sup>

*Sums total of possible duration of sunshine, in hours, from January 1 up to any day of the year.*

Interval.	Num- ber of days.	Latitude.						
		24°.	26°.	28°.	30°.	32°.	34°.	36°.
		<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>
January 1-10 .....	10	106.7	105.4	104.0	102.5	101.0	99.4	97.7
January 11-20 .....	10	214.5	212.0	209.3	206.4	203.5	200.4	197.2
January 21-31 .....	11	334.7	331.0	327.1	322.9	318.7	314.2	309.5
February 1-10 .....	10	446.0	441.4	436.6	431.4	426.2	420.6	414.9
February 11-20 .....	10	559.4	554.1	548.6	542.6	536.7	530.2	523.7
February 21-28 .....	8	649.9	645.2	640.3	633.9	627.6	620.6	613.6
March 1-10 .....	10	767.4	762.4	757.2	750.5	743.8	736.4	729.0
March 11-20 .....	10	887.2	882.1	876.8	870.0	863.2	855.7	848.2
March 21-31 .....	11	1,021.7	1,016.8	1,011.7	1,005.0	998.4	991.1	983.7
April 1-10 .....	10	1,146.4	1,141.9	1,137.2	1,130.9	1,124.7	1,117.9	1,110.9
April 11-20 .....	10	1,273.3	1,269.4	1,265.3	1,259.7	1,254.2	1,248.1	1,241.8
April 21-30 .....	10	1,402.3	1,399.2	1,396.0	1,391.3	1,386.7	1,381.5	1,376.2
May 1-10 .....	10	1,533.3	1,531.2	1,529.0	1,525.4	1,521.9	1,517.9	1,513.8
May 11-20 .....	10	1,666.0	1,665.1	1,664.1	1,661.8	1,659.6	1,657.0	1,654.3
May 21-31 .....	11	1,813.6	1,814.1	1,814.6	1,813.8	1,813.2	1,812.4	1,811.4
June 1-10 .....	10	1,948.8	1,950.7	1,952.7	1,953.4	1,954.4	1,955.3	1,956.0
June 11-20 .....	10	2,084.5	2,087.9	2,091.4	2,093.7	2,096.3	2,099.0	2,101.5
June 21-30 .....	10	2,220.2	2,225.1	2,230.1	2,234.0	2,238.2	2,242.7	2,247.0
July 1-10 .....	10	2,355.4	2,361.7	2,368.2	2,373.6	2,379.4	2,385.6	2,391.6
July 11-20 .....	10	2,490.7	2,497.3	2,505.2	2,512.0	2,519.3	2,527.1	2,534.7
July 21-31 .....	11	2,636.0	2,644.9	2,654.1	2,662.3	2,671.0	2,680.4	2,689.6
August 1-10 .....	10	2,767.1	2,777.1	2,787.3	2,796.6	2,806.4	2,817.0	2,827.5
August 11-20 .....	10	2,896.3	2,907.1	2,918.1	2,928.3	2,939.0	2,950.6	2,962.1
August 21-31 .....	11	3,036.1	3,047.5	3,059.2	3,070.2	3,081.7	3,094.1	3,106.4
September 1-10 .....	10	3,160.8	3,172.6	3,184.7	3,196.1	3,208.0	3,220.9	3,233.6
September 11-20 .....	10	3,283.2	3,295.2	3,307.4	3,319.0	3,331.1	3,344.2	3,357.1
September 21-30 .....	10	3,403.3	3,415.2	3,427.4	3,439.0	3,451.0	3,464.0	3,476.9
October 1-10 .....	10	3,521.1	3,532.7	3,544.6	3,555.9	3,567.6	3,580.2	3,592.8
October 11-20 .....	10	3,636.6	3,647.7	3,659.1	3,669.9	3,681.0	3,693.0	3,705.0
October 21-31 .....	11	3,761.2	3,771.5	3,782.1	3,792.1	3,802.3	3,813.4	3,824.5
November 1-10 .....	10	3,872.3	3,881.7	3,891.3	3,900.3	3,909.4	3,919.4	3,929.4

<sup>a</sup> Omitted.



*Sum total of possible duration of sunshine, in hours, from January 1 up to any day of the year—Continued.*

Interval.	Num- ber of days.	Latitude.						
		24°.	26°.	28°.	30°.	32°.	34°.	36°.
		<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>
November 11-20 .....	10	3,981.5	3,989.8	3,999.8	4,006.1	4,014.0	4,022.7	4,031.4
November 21-30 .....	10	4,089.3	4,096.2	4,104.3	4,109.9	4,116.5	4,123.7	4,130.9
December 1-10 .....	10	4,196.0	4,201.6	4,208.3	4,212.4	4,217.5	4,223.1	4,228.6
December 11-20 .....	10	4,302.2	4,306.4	4,311.6	4,314.1	4,317.6	4,321.5	4,325.3
December 21-31 .....	11	4,418.9	4,421.5	4,425.1	4,425.9	4,427.7	4,429.7	4,431.6
For leap year add to all num- bers after February 28 .....		11.8	11.4	11.5	11.5	11.4	11.8	11.2
January 1—December 31, 1905 .....		4,436.5	4,438.1	4,439.9	4,441.1	4,444.6	4,445.8	4,448.6

Interval.	Num- ber of days.	Latitude.						
		38°.	40°.	42°.	44°.	46°.	48°.	50°.
		<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>
January 1-10 .....	10	95.8	94.0	91.9	89.8	87.4	84.8	82.0
January 11-20 .....	10	193.6	190.2	186.2	182.1	177.5	172.6	167.2
January 21-31 .....	11	304.2	299.2	293.4	287.5	280.8	273.6	265.8
February 1-10 .....	10	406.4	402.2	396.1	387.8	379.6	370.7	361.1
February 11-20 .....	10	516.8	509.2	501.1	492.7	483.3	473.2	462.3
February 21-28 .....	8	605.7	598.2	589.5	580.5	570.5	559.7	548.1
March 1-10 .....	10	720.7	712.8	703.7	694.2	683.7	672.4	660.2
March 11-20 .....	10	839.8	831.8	822.6	813.0	802.4	791.0	778.7
March 21-31 .....	11	975.4	967.6	958.7	949.8	938.9	927.8	915.9
April 1-10 .....	10	1,103.2	1,095.9	1,087.5	1,078.7	1,068.0	1,056.6	1,044.5
April 11-20 .....	10	1,234.9	1,226.4	1,220.9	1,213.0	1,204.3	1,195.0	1,185.1
April 21-30 .....	10	1,370.4	1,365.0	1,358.7	1,352.0	1,344.6	1,336.8	1,328.5
May 1-10 .....	10	1,509.3	1,505.3	1,500.5	1,495.4	1,489.7	1,483.7	1,477.4
May 11-20 .....	10	1,651.8	1,648.9	1,645.9	1,642.6	1,639.0	1,635.2	1,631.3
May 21-31 .....	11	1,810.3	1,809.9	1,809.0	1,808.0	1,807.0	1,805.9	1,805.1
June 1-10 .....	10	1,956.9	1,958.4	1,959.7	1,961.0	1,962.5	1,964.1	1,966.3
June 11-20 .....	10	2,104.4	2,107.9	2,111.4	2,115.1	2,119.2	2,123.7	2,129.1
June 21-30 .....	10	2,251.9	2,257.4	2,263.2	2,269.3	2,276.0	2,283.4	2,292.0
July 1-10 .....	10	2,398.5	2,406.0	2,413.9	2,422.3	2,431.5	2,441.7	2,453.4
July 11-20 .....	10	2,543.4	2,552.7	2,564.6	2,573.2	2,584.7	2,597.4	2,611.9
July 21-31 .....	11	2,700.1	2,711.2	2,725.1	2,735.8	2,749.6	2,764.7	2,782.0
August 1-10 .....	10	2,839.3	2,851.7	2,867.1	2,879.4	2,894.9	2,911.9	2,931.3
August 11-20 .....	10	2,975.0	2,988.5	3,005.1	3,018.8	3,035.7	3,054.2	3,075.2
August 21-31 .....	11	3,120.2	3,134.7	3,152.3	3,167.0	3,185.0	3,204.8	3,227.2
September 1-10 .....	10	3,248.0	3,263.0	3,281.1	3,296.5	3,315.1	3,335.6	3,358.8
September 11-20 .....	10	3,371.8	3,387.0	3,405.3	3,421.0	3,439.9	3,460.7	3,484.2
September 21-30 .....	10	3,491.5	3,506.6	3,524.9	3,540.5	3,559.3	3,570.0	3,603.4
October 1-10 .....	10	3,607.1	3,621.8	3,639.7	3,654.9	3,673.3	3,693.5	3,716.4
October 11-20 .....	10	3,718.7	3,732.7	3,749.9	3,764.4	3,782.0	3,801.3	3,823.2
October 21-31 .....	11	3,837.2	3,850.2	3,866.3	3,879.6	3,895.9	3,913.7	3,934.2
November 1-10 .....	10	3,940.9	3,952.7	3,967.5	3,979.3	3,994.1	4,010.2	4,028.9
November 11-20 .....	10	4,041.4	4,051.7	4,064.8	4,074.9	4,087.9	4,101.9	4,118.3
November 21-30 .....	10	4,139.2	4,147.8	4,159.0	4,167.1	4,178.0	4,189.6	4,203.5
December 1-10 .....	10	4,235.0	4,241.8	4,251.0	4,256.9	4,265.3	4,274.4	4,285.5
December 11-20 .....	10	4,329.8	4,334.7	4,341.7	4,345.3	4,351.2	4,357.6	4,365.7
December 21-31 .....	11	4,434.0	4,436.8	4,441.4	4,442.5	4,445.7	4,449.0	4,453.8
For leap year add to all num- bers after February 28 .....		11.2	11.1	11.0	11.0	10.9	10.8	10.8
January 1—December 31, 1905 .....		4,451.5	4,454.3	4,457.4	4,461.5	4,465.7	4,470.8	4,476.7

**Chapter VI.**  
**MOISTURE OF THE SOIL.**  
**IN GENERAL.**

The soil receives its water supply either by natural rainfall or by irrigation. The plant in successive generations of cultivation adapts itself to the ordinary supply of water, but in order to perpetuate its kind it must have sufficient during the growing season to serve it as a medium for extracting from the soil and air the nutritious substances needed by it for its own development. The water really available to the plant is principally that which is left in the soil close to the roots after the surface drainage has carried off a large per cent of the original rainfall and after the evaporation by the dry wind has taken 20 per cent of the remainder from the surface soil and after a further large per cent of the remainder has by percolation or seepage slowly settled down beyond the reach of the roots of the plant. Thus it happens that the roots rarely have left for their use 20 per cent of the original rainfall, and this is the so-called "useful remainder." Generally this remainder is best expressed as a percentage of what the soil would hold were it completely saturated. Therefore its absolute quantity will vary with the character of different soils

**EVAPORATION FROM THE SURFACE OF FRESH WATER.**

**MONTSOURIS DATA FROM DESCROIX.**

An approximate idea of the relation between the velocity of the wind, its temperature, and its dryness, on the one hand, and its power to evaporate water on the other, may be obtained by collating the data given by Descroix in his article on "The climatology of Paris," in the Montsouris Annuaire, 1890, page 121. From the mass of data given by him I select the averages taken according to the direction of the wind, or wind roses, for the three summer months June, July, and August, 1889, as these are the months during which crops are liable to suffer the most severely from droughts and dry winds. I give them in the following table:

*Summer wind roses of evaporation at Montsouris.*

Wind.			Average daily tempera- ture.	Daily minima of rela- tive hu- midity.	Evapo- ration daily.	Total rainfall.
Direction.	Number of days.	Hourly velocity.				
		<i>Sec. kilo.</i>	<i>° C.</i>	<i>Per cent.</i>	<i>mm.</i>	<i>mm.</i>
From north .....	8	12.8	18.24	45.9	6.35	0.0
From northeast .....	8	14.6	19.02	46.4	5.71	4.4
From east .....	5	10.1	20.54	45.4	4.72	0.0
From southeast .....	4	7.2	20.08	47.8	4.15	0.0
From south .....	10	11.0	19.71	55.2	2.87	45.8
From southwest .....	20	15.4	18.72	51.9	3.54	39.3
From west .....	20	14.2	17.21	50.8	3.60	23.8
From northwest .....	12	11.2	17.00	51.8	3.70	10.4
Various .....	5	14.8	17.76	46.6	3.17	0.7
Three months .....	92					124.4

We see that the driest winds, or those whose relative humidity is small, such as the north and east winds, give a large evaporation, and that the velocity and temperature of the west winds, which are a little less than those of the southwest winds, does not compensate for the dryness, which latter enables them to evaporate a little less than the southwest winds.

By multiplying the average daily evaporation by the number of days we obtain the total evaporation from the saturated paper of the Piche instrument. This exceeds the total rainfall, but we are not to infer that the evaporation from ground and leaves must also necessarily exceed the rainfall, although this is generally true for the summer season.

## BOSTON DATA FROM E. J. FITZGERALD.

The evaporation of the water from leaves and from the ground depends upon the temperature, wind, and humidity of the air. It is a rather complex result; if the above-mentioned elements remain constant for any time at the surface of the mass of water the evaporation from that surface will be closely represented by the following formula which is due to Fitzgerald, of Boston,

$$E=0.0166 (P-p) (1+\frac{1}{4} W),$$

where  $W$  is the velocity of the wind in miles per hour;  $P$  the tension of vapor in inches of mercury corresponding to the temperature of the water;  $p$  is the tension of vapor corresponding to the dew point in the free air;  $E$  is the evaporation expressed in inches of depth of water evaporated per hour under atmospheric pressure between 29 and 31 inches of the barometer.

The evaporation from leaves and soils is usually less than that from water about in the proportion in which the soil approximates its

state of maximum saturation, or in proportion as the leaf can transpire moisture through its cell walls.

Therefore any observations of evaporation that we may make for comparative purposes can give us only the relative evaporating power of the wind and not the absolute evaporation from plants and soils.

THE PICHE EVAPORIMETER.

The simplest apparatus for observing evaporation is that known as the Piche evaporimeter. This consists of a glass tube closed at the top and hung in a free exposure; the tube is less than half an inch in diameter and filled with water; its lower open end is closed by a horizontal disk of bibulous paper about twice the diameter of the tube; the water evaporated from this paper is supplied from within the tube. The observer has simply to read the height of the water in the tube as it slowly descends hour by hour. The number so read off is easily converted into one that expresses the depth of water evaporated per hour from unit surface.

The following table from Montsouris Annuaire, 1888, page 254, shows the average evaporation thus determined by an instrument placed in the shade, also the corresponding temperatures and other data, as observed at Montsouris during thirteen years.

Evaporation at Montsouris.

[Averages for 1873-1885.]

Month.	Number of days.	Temper- ature of air in shade.	Tension of vapor in air.	Relative hu- midity.	Hourly velocity of wind.	Hourly evapora- tion.
		°C.	mm.	Per cent.	Kilom.	mm.
January .....	164	3.6	4.8	80.9	15.9	0.084
February .....	203	6.0	5.4	77.0	16.1	.101
March .....	281	9.1	5.4	62.9	17.8	.187
April .....	324	12.7	6.3	57.3	17.6	.225
May .....	341	16.2	7.4	54.0	17.5	.257
June .....	330	20.0	10.1	58.2	15.3	.282
July .....	341	22.0	11.1	56.5	14.7	.254
August .....	341	21.6	11.4	59.4	15.7	.284
September .....	330	17.6	10.2	68.0	14.4	.154
October .....	340	12.5	8.0	73.8	15.4	.099
November .....	284	8.0	6.2	77.5	18.1	.091
December .....	219	3.6	4.9	82.4	15.6	.063

THOMAS RUSSELL'S OBSERVATIONS.

Prof. Thomas Russell, of the Signal Office, has published results of some observations on the effect of the wind on the evaporation from the disks of the Piche evaporimeter. (See Annual Report Chief Signal Officer, 1888, p. 176, or Monthly Weather Review, 1888,

p. 235.) He finds that with the temperature of the air 84° F. and a relative humidity 50 per cent the evaporation varies with the velocity of the wind at the surface of the moist disk as in the following paragraph:

INFLUENCE OF THE WIND ON EVAPORATION.

At 5 miles an hour the evaporation is 2.2 times that in a calm; at 10 miles, 3.8 times; at 15 miles, 4.9 times; at 20 miles, 5.7 times; at 25 miles, 6.1 times; at 30 miles, 6.3 times.

The observations of the Piche instruments, as exposed in Signal Service shelters at 18 different stations, gave the results in the table following. (See Monthly Weather Review, September, 1888, p. 236.) The readings on the scale of the Piche instrument have been converted into depths of water that would be evaporated from a free surface of water within the same instrument shelter during the respective months by multiplying them by the constant coefficient 1.33, so that the evaporations here given in inches of depth of water correspond entirely to the ordinary methods of measuring rainfall.

*Evaporation, in inches, observed with Piche instruments within the Signal Service thermometer shelters in 1888.*

Station.	June.	July.	August.	September.
	<i>Inches.</i>	<i>Inches.</i>	<i>Inches.</i>	<i>Inches.</i>
Boston.....	5.16	5.87	5.28	2.68
New York.....	4.49	5.36	4.14	2.88
Washington.....	4.64	5.27	4.22	2.52
Buffalo.....				3.70
Cincinnati.....	6.22	6.98	5.36	5.88
Memphis.....	5.83	5.24	4.57	3.86
New Orleans.....	3.82	9.38	7.96	3.70
Chicago.....	5.59	5.52	6.97	5.79
St. Louis.....	6.18	5.79	4.41	4.61
Keeler.....	11.68	12.76	12.69	10.95
Yuma.....	13.86	13.68	12.88	10.86
El Paso.....	13.91	9.89	11.54	10.00
Dodge City.....	7.80	8.20	6.22	6.07
San Antonio.....	2.76	5.08	5.36	3.66
Omaha.....	7.01	6.62	5.44	6.78
Denver.....	9.42	10.91	8.55	5.94
St. Vincent.....	5.63	4.38	5.97	.....
Helena.....	4.88	8.20	7.80	6.86
Boise City.....	5.83	9.14	7.68	(a)

\* In October at Boise City the evaporation was 7.60 inches.

Profesor Russell has also devised the following very satisfactory formula connecting the total daily evaporation in inches with the meteorological elements on which it depends, viz, the vapor tensions,  $p_w$  for mean wet bulb and  $p_d$  for mean dew-point temperatures, ( $b$ ) barometric pressure, by means of which he has been able to compute

the possibilities of evaporation within Signal Service shelters over the whole country for an average wind velocity.

$$\text{Daily evaporation} = \frac{30}{6} \left[ 1.96 p_w + 43.9 (p_w - p_a) \right]$$

His results in this respect are platted on chart No. VI of the Monthly Weather Review, September, 1888, and show that the total annual depth of evaporation has its maximum of over 90 inches in southern Arizona, California, and New Mexico, whence it diminishes to a minimum of 20 inches annually in the northwest corner of the State of Washington and thence eastward to Maine. These figures, like his formula, take no account of the wind, because within the Signal Service shelters the wind is reduced to a velocity far less than that in the open air. These figures, therefore, represent the evaporation in open air only when there is no wind above some small limit—say 6 miles per hour but may be adapted to strong winds by the use of the figures given in the first paragraph of this section.

#### **CULTIVATION DIMINISHES SURFACE-SOIL EVAPORATION.**

The general effect of cultivation is to pulverize the upper soil; this protects the capillary roots from surface exposure, it breaks up the capillary outlets of the moisture in the soil, checks the natural evaporation that goes on at the surface, and thus preserves the water within the soil for the use of the plants. Dr. E. L. Sturtevant's observations show that the extent to which the water is thus conserved by cultivation during the months from May to September, 1885, at Geneva, N. Y., may be thus expressed: With a rainfall of 14.42 inches the cultivated soil evaporated 1.4 inches less than the uncultivated naked soil and 2.25 inches less than the soil covered with sod. In other words, the efficiency of the soil to retain useful water is increased by cultivation to an extent equivalent to 10 per cent of the rainfall. If the capillary connections between the soil in the neighborhood of the roots and the supply of moisture lower down be broken no supply of moisture can come up from below, but if the soil be well rolled the compacting will aid the capillary attraction and the plants will secure moisture from below. Again, when weeds are allowed to grow freely the injury to the crops is not due to robbing the soil of nutrition nor to their shading the ground, but principally to their robbing the soil of its moisture. Those who can with impunity allow weeds to grow must have soils containing an excessive moisture, which they thus get rid of, while those who have a comparatively dry soil must destroy the weeds in order to reserve moisture for the use of their crops. (Agr. Sci., Vol. I, p. 216.)

**PERCOLATION.**

The permeation of water through soils of different qualities has been studied by Welitschkowsky (Wollny, 1888, X, p. 203.) He maintained a layer of water at a constant height above the material through which it permeated; therefore the pressure forcing the water through was constant. He found that the quantity of flow increased at first rapidly, then slowly for several days, depending on the thickness of the stratum of soil and the pressure of the water, until the permeation reached the maximum; then the rate of flow diminished slightly for a day or two until it became constant. He found that the quantity of water delivered in a unit of time has no simple relation to the pressure forcing it through the soil or to the thickness of the layer of soil through which it flows, but the relation is more nearly expressed as follows: If the pressure be increased by regular additions the flow of water increases in an arithmetical progression such that the quantity equals (A) plus a constant factor (D) times the pressure (P) less unity;  $A + D (P - 1)$ . The numerical values of these terms can be deduced from his extensive tables of experiments, of which the following table is an abstract:

Soil.	Size of grains.	Maximum capacity for water. <sup>a</sup>	Intensity of flow, in liters, per minute.					
			Layer of soil 50 cm. thick.			Layer of soil 100 cm. thick.		
			Head of water pressure.			Head of water pressure.		
			10 cm.	50 cm.	100 cm.	10 cm.	50 cm.	100 cm.
	mm.							
Fine sand .....	0.88	90.86	0.00018	0.00022	0.00081	-----	-----	-----
Average sand .....	0.88-1.0	71.46	0.106	0.179	0.278	0.006	0.126	0.167
Coarse sand .....	1.0-2.0	52.59	1.172	1.886	2.776	1.011	1.849	1.789
Small gravel .....	2.0-4.0	19.87	6.747	9.594	13.187	6.486	8.084	10.015
Average gravel .....	4.0-7.0	18.44	11.708	16.847	-----	11.015	13.555	-----

<sup>a</sup> The capacity for water is expressed as a percentage of the weight of the dry soil.

The general laws of the flow of waters through soils of different natures have been elaborately investigated by Milton Whitney in a series of papers published in *Agricultural Science*, Volume IV, to which the reader must refer for the details.

The percolation of water through the soil, whether it goes downward as drainage or upward to be evaporated from the surface, depends not merely upon the degree of comminution of the soil and its compactness, but also, among other things, to a slight extent, upon the barometric pressure of the atmosphere, so that a falling barometer is, according to E. S. Goff, generally accompanied by a corresponding increase in the rate of drainage or of percolation downward. (*Agr. Sci.*, Vol. I, p. 173.)



**AVAILABLE MOISTURE.**

In his investigations as to the relation of atmospheric precipitation, especially rainfall, to the plants and the soil, Wollny shows that the percentage of water in the layer of soil containing growing plants increases from above downward as soon as the downward movement of the rain water in the soil ceases, but that the percentage increases from below upward while the rain is falling and so long as the water continues to be penetrating downward. The frequency of rainfall is of even greater importance than the quantity. Slight rainfalls that only wet the soil to the depth of a few millimeters do but little good to the vegetation, because the greater part of the water is quickly evaporated back again into the atmosphere. If it should rain daily 2 millimeters during the three summer months, then, even with this abundant precipitation the plants might die for want of water, whereas if this total of 180 millimeters were uniformly divided into ten or twelve rains during the three summer months it would be considered a remarkably favorable growing season, since under these conditions the earth would be wet down to a considerable depth and the water thus stored up is protected from evaporation. Therefore, for equal quantities of rain its value for agriculture increases as the number of rainy days diminishes, and diminishes as the number of rainy days increases, at least up to a limit that varies with the character of the soil.

In order to attain precise ideas on this subject, Haberlandt set out a series of glass tubes full of dry earth; each received at the beginning a certain quantity of water, and by weighing these from day to day he determined the loss due to evaporation. These losses are given in the following table, in percentages of the original quantity of water, which latter may be considered as a rainfall whose depth is given at the top of the column:

Date.	1.	2.	3.	4.	5.	6.
Initial rainfall September 20 in millimeters.....	2.22	6.67	18.83	26.67	40.00	58.33
<i>Loss by evaporation in percentages.</i>						
September 21.....	94.75	99.51	26.34	14.78	9.81	8.96
September 22.....	5.68	17.02	10.22	10.09	7.75	7.48
September 23.....		18.85	14.87	13.89	10.83	9.05
September 24.....		12.16	14.56	11.82	8.99	8.09
September 25.....		7.29	6.20	7.30	5.27	7.05
September 26.....		3.04	6.82	8.17	6.92	6.70
September 27.....		1.82	5.89	8.48	8.51	3.48
September 28.....			5.58	8.65	2.58	8.04
September 29.....			4.84	2.96	1.86	2.61
September 30.....			2.48	1.74	1.76	2.00
October 5.....			2.79	5.55	6.31	7.22
October 10.....				2.09	2.89	2.95
Total in 20 days.....	100.43	99.69	100.09	85.02	67.98	68.63

These experiments give us some idea as to what percentage of the rainfall remains in the soil for the use of the plant in the case of large and small rains, but do not quite answer the question how one and the same quantity of rain is utilized in moistening the earth when it is distributed through a larger or smaller number of rainy days.

On this latter question Wollny has made the following experiment: A quantity of water corresponding to a rainfall of 60 millimeters was communicated to an experimental tub, No. 1, all at once, while in tub No. 2, 30 millimeters were given the first time and the remaining 30 after three days; in the third tub 20 millimeters were given at first and 20 millimeters every other day thereafter, and, finally, in the fourth tub, 10 millimeters were given every day, so that in six days all had received the same quantity of water. These experiments were repeated for different kinds of soil and the results show that in all cases the quantity of water lost by evaporation is larger the more frequently the water was communicated or the greater the number of rainy days. A fine illustration of the truth of this principle as applied to practice is narrated by Haberlandt, who found that in 1874 the farmers at Postelberg got much better crops than those at Lobositz, which could only be attributed to the fact that during that year Postelberg had received 246 millimeters of rainfall in forty days, or an average of 6, whereas Lobositz had received 309 millimeters in seventy-seven days, an average of 4, so that the usefulness of the greater quantity of rain in Lobositz did not equal that of the smaller quantity at Postelberg.

Wollny shows that since the period of the heaviest rainfall occurs throughout central Europe at the time of the largest evaporation from the soil we must conclude that for the naked earth the wetting of the soil during the warmer season of the year is controlled much more largely by the rainfall than by the evaporation depending on the temperature. His observations with the lysimeter show that the precipitation is principally concerned in the moistening of the naked soil during the warmer season, while the influence of the temperature and the resulting evaporation nearly disappears and is only observable in periods that are deficient in rain. In most cases the vegetation is injured when the atmospheric precipitation during the coldest season of the year is insufficient. The precipitation at this time of the year is therefore quite as important for the success of the harvest as that which falls during the period of vegetation. (Wollny's *Forschungen*, Vol. XIV, pp. 138-161.)

A. Seignette has shown that the law of levels propounded by Royer is confirmed. This law states that for given plants and for other uniform conditions the reserve nutriment in the earth is always found at a constant distance below the surface; thus the bulbs of

a plant under given conditions are found at a given level, and if we change these conditions as to moisture, temperature, etc., we shall change the distance from the surface down to this level. (Wollny's *Forschungen*, Vol. XIV, p. 132.)

### TRANSPIRATION.

The quantity of water transpired by trees and plants depends upon the amount of water at their disposal, as well as on the temperature and dryness of the air, the velocity of the wind, the intensity of sunlight, the stage of development of the plant, the amount of its foliage, and the nature of its leaf. The following are some of the results of measurements at European experiment stations. (See Fernow, Report, 1889, p. 314.)

F. B. Hoehner found that the transpiration per day per 100 grams of dry weight of leaves is for conifers 4.778 to 4.990 grams, but for deciduous trees about ten times as much, 44.472 to 49.553. During the whole period of vegetation a unit weight of dry leaves corresponded to a total weight of evaporated water, as shown by the following table, for three different years.

*Transpiration of water corresponding to growth of unit weight of dry leaves.*

Plant.	1878.	1879.	1880.	Plant.	1878.	1879.	1880.
Birch and linden.....	650	1,000	90	Oaks .....	250	400	50
Ash .....	550	700	101	Spruce and Scotch pine.	60	150	13
Beech .....	475	600	91	Fir .....	85	100	9
Maple .....	425	550	70	Black pine .....	85	75	7

The variability of transpiration is shown by the action of a birch in the open air, which transpired on a hot summer day from 700 to 900 pounds, while on other days it probably transpired not more than 18 to 20 pounds. A beech about 60 years old had 35,000 leaves, whose total dry weight was 9.86 pounds; hence its transpiration, at the rate of 400 pounds of water per pound of leaves, would be 22 pounds daily. An acre containing 500 trees would, during the total period of vegetation, transpire nearly 2,000,000 pounds of water, or about 50 pounds to the square foot.

A younger beech, thirty-five years old, with 3,000 leaves and a dry weight of 0.79 pounds, would, under the same conditions, transpire 470 pounds per pound or 2½ pounds per day from June to November. An acre containing 1,600 such trees would transpire about 600,000 pounds per acre or 15 pounds to the square foot from June to November.

Of the entire mass of wood and foliage on an acre of forest from 56 to 60 per cent of the weight is water and 44 to 40 per cent dry sub-

stance. In agricultural crops the amounts of water are still larger, sometimes reaching 95 per cent of the whole weight.

The amounts transpired by cereals, grasses, weeds, etc., are considerably larger than the preceding, as shown by the following table compiled from Wollny's results:

Plant.	Year.	Begin- ning of vegeta- tion.	End of vegeta- tion.	Water consump- tion per acre.	
				Pounds.	Inches.
Winter rye .....	1879	Apr. 20	Aug. 3	2,590,000	10
Barley .....	1879	do	do	2,720,000	11
Peas .....	1879	do	do	3,140,000	12
Red clover .....	1879	do	Oct. 1	3,070,000	12
Summer rye .....	1880	do	Aug. 14	3,000,000	12
Oats .....	1880	do	Sept. 14	3,420,000	14
Beans .....	1880	do	Sept. 10	3,140,000	12
Red clover .....	1880	do	Oct. 1	4,110,000	16

The following table is given by Risler (1873) in his "Note on the diminution of the volume of water courses," and shows the mean daily consumption of water by plants, expressed in millimeters of depth of water over the area of the field:

Plant.	Daily con- sumption of water.	Plant.	Daily con- sumption of water.
	<i>mm.</i>		<i>mm.</i>
Lucerne grass .....	3.4....7.0	Clover .....	2.9
Prairie grass .....	3.1....7.3	Rye .....	2.3
Oats .....	2.9....4.9	Vine .....	0.9....1.3
Beans .....	3.0+	Potatoes .....	0.7....1.4
Maize .....	2.8....4.0	Pine forest .....	0.5....1.1
Wheat .....	2.7....2.8	Oak forest .....	0.5....0.8

These numbers have been deduced from the results of many years of experiments in the laboratory and from observations made in a drained field under conditions favorable to this kind of research. The crops have necessarily varied from one year to another, but unfortunately I am not acquainted with these details.

The transpiration of the plant is only a means to an end. (See Marié-Davy, 1875, p. 209.) Its object is the introduction into the vegetable organism of the mineral elements necessary for the development of its tissues and that of the other principles united there. The experiments of Woodward and those of Lawes have already shown us that the same quantity of water is not always necessary in order to furnish the same amount of mineral substance and to produce in the plant all the elaboration and movements of organic products which should be produced there.

It appears evident that in soils more or less fertile and which con-

tain in unequal quantities soluble and nourishing principles the water absorbed by the roots may be more or less charged with these elements. We can understand, then, that the quantity of water necessary to enable a plant to furnish a given result is not the same for all soils, and that the richest soils may produce a greater result with a proportionably smaller consumption of water. By increasing the richness of the soil in soluble substances that can be assimilated, we should succeed in economically reducing the quantity of water consumed by the crops. In any case we might at the same time ask ourselves if all the water absorbed by the roots and introduced into the plant is utilized by it and at what limit the richness of the water should be arrested so as to be really profitable to the plant. In this connection Marié-Davy cites the following fact, mentioned by Perret in the *Journal of Practical Agriculture* for 1873:

In Perret's experiments a meadow having been covered with a sufficient quantity of nitrate of soda for a nitrogenous manuring of four years, the grass was magnificent in the spring. This grass was given green to the horses, who before long began to show strong diuretic symptoms accompanied by raging thirst. These animals seemed to be completely under the influence of the administration of a strong dose of nitrate. The following year there was a complete cessation of the beneficial effects of the nitrate on the meadow, which showed conclusively that the plants of the first year contained nitrate in a natural state and not decomposed by the assimilation.

When nutritive substances are given to plants in abundance they can absorb a quantity of these elements besides what is necessary for their nourishment. This is particularly true when in the series of minerals which compose a normal nourishment, one of these substances is in excess of the others. Besides, if we compare the chemical composition of a crop cut green with that of a similar crop after arriving at maturity, we find that in the latter there is a diminution in weight of several of the substances present in the former. It would, therefore, have been interesting to know if the trouble mentioned by Perret was continued with the same intensity in the dry hay.

#### **RELATION OF PLANTS TO MOISTURE OF SOIL.**

E. Wollny (1887, Vol. X, p. 320) gives some results as to the influence of plants and shade on the moisture of the soil, being a modification of a memoir published by him in 1877. His conclusions are as follows:

(1) The water contained in the soil under a covering of living plants is, during the growing season, always less than in a similar layer of fallow, naked soil.

(2) The cause of the drying up of the soil by the plants is to be found in the very considerable transpiration of aqueous vapor by their leaves.

(3) The plants deprive the soil of water in proportion as they stand closer together and have developed their tops more luxuriantly.

(4) The influence of the vegetation on the moisture of the soil extends to the deeper layers of soil.

(5) The moisture of the soil under a layer of inert objects, such as dead plants, manure, straw, pieces of wood, windfalls, etc., is always greater than that of the uncovered soil.

(6) The retention of the moisture in the soil under a cover of dead matter is a consequence of the protection afforded by the latter against the influences that favor evaporation.

(7) The quantity of moisture in the soil is, within certain limits and to a depth of about 5 centimeters, or 2 inches, greater in proportion as the covering of dead matter is thicker.

(8) The soil shaded by living plants is, under otherwise similar conditions, driest during the growing period, but that covered by dead objects is the moistest, while that which is not cultivated, not covered with plants and naked, is midway between the two previous in reference to its relations to moisture.

Wollny has also studied the influence of plants and shade upon the drainage of water from the soil. His conclusions are:

(1) A notably smaller quantity of water drains through the soil supporting living plants from the same quantity of rainfall than through a naked soil during the growing season.

(2) The quantity of drainage in cultivated fields is less in proportion as the plants stand more closely together and in proportion as they have developed themselves more luxuriantly.

(3) The quantity of drain water from a soil covered by inert objects is increased in comparison with that from fallow land in proportion as the covering layer is thicker, up to a certain limit, up to about 5 centimeters, beyond which a further increase in the thickness of the covering steadily diminishes the quantity of drainage water.

(4) For the same quantity of rain and under otherwise similar circumstances, the soil covered with dead leaves and similar objects furnishes the greatest quantity of drainage water up to a covering of about 5 centimeters thickness; the naked, fallow land furnishes the next smaller quantity of water; the soil covered with living plants furnishes the least quantity of drain water.



## RELATION OF WATER TO CROPS.

E. Wollny has studied the relation of the irrigation and rainfall to the development and productive power of plants in cultivated fields, and the following summary is essentially as given by him in Volume X of his *Forschungen* for 1888, page 153.

An early investigation of this subject was made by Ilionkoff, who filled five large tubs with soil and sowed buckwheat in each on the 15th of May; each tub was then watered regularly with a definite quantity of water, the total quantity used being given in the second column of the table following. The relative quantities of buckwheat harvested at the end of the season are given in the third column and the straw is given in the fourth column. The weight of the buckwheat originally sown in each tub was the same, viz, 0.154 gram.

Tub No.—	Total water ap- plied.	Weight of green har- vest.			Weight of dry harvest.		Num- ber of ker- nels har- vested.	Ratio of straw and kernels to the seed.
		Grain.	Straw.	Sum total.	Grain.	Straw.		
	<i>Liters.</i>		<i>Grams.</i>	<i>Grams.</i>	<i>Grams.</i>	<i>Grams.</i>		
1 .....	25.00	1.89	28.10	27.99	1.68	4.52	111	45
2 .....	12.50	6.15	58.85	65.00	5.47	8.47	283	100
3 .....	6.25	1.95	23.08	24.98	1.73	4.55	93	46
4 .....	3.12	.58	9.42	10.00	.52	1.41	87	14
5 .....	1.56	.10	2.20	2.30	.09	.30	12	3

These figures show plainly that the plants in tub No. 2 were most favorably situated. Probably No. 1 had too much water and Nos. 3, 4, and 5 too little.

Haberlandt, in 1866, experimented on the quantity of water needed in the growth of plants in three plats of 14.41 square meters each; of these No. 1 received no artificial watering; No. 2 was watered once a week, except in great droughts twice a week; No. 3 received a double quantity once a week. These quantities corresponded to a rainfall of 6.46 millimeters for No. 2 and 13.92 millimeters for No. 3. The total quantities for the season were 96.96 and 193.92 millimeters. The natural rainfall was as follows:

Month, 1886.	Rainy days.	Rainfall.
		<i>mm.</i>
March .....	17	40.98
April .....	15	35.88
May .....	11	52.20
June .....	13	46.08
July .....	17	84.40
Total .....	73	208.99



The number of rainy days was large, but the rainfall was small, and the plants in bed No. 1 suffered for want of water. The relative harvests for the different beds and crops were as follows:

Plant and bed.	Harvest (relative numbers).		Plant and bed.	Harvest (relative numbers).	
	Grain.	Straw.		Grain.	Straw.
<b>Wheat:</b>			<b>Barley:</b>		
1.....	100	100	1.....	100	100
2.....	138	129	2.....	109	105
3.....	172	164	3.....	216	123
<b>Rye:</b>			<b>Oats:</b>		
1.....	100	100	1.....	100	100
2.....	136	124	2.....	133	116
3.....	161	219	3.....	182	126

Beds Nos. 1 and 2 showed about the same rate of growth. No. 3 showed a retardation. The barley and the rye were harvested from this bed four days later than from the other two. The quantity of harvest increased with the quantity of water, and the harvest of grain, except in the case of the wheat, was more increased by watering than was the harvest of straw; the quality of the grain showed only slight differences.

Hellriegel experimented (1867-1883) on the influence of water upon the crops. He filled a number of vessels with quartz sand and maintained the earth at a different state of dryness. The experiments were repeated for several years on wheat, rye, and oats, the general results being that when the ground contained from 60 to 80 per cent of its full capacity of water the harvest was larger than when the ground was drier and about in the following proportions:

Tub.	Moisture.	Wheat crop.		Rye crop.		Oat crop.	
		Straw.	Grain.	Straw.	Grain.	Straw.	Grain.
	<i>Per ct.</i>						
1	80-60	22	11.0	16	10	16	12
2	60-40	21	10.0	15	10	14	11
3	40-20	15	8.0	12	8	12	8
4	20-10	7	2.8	12	4	4	2

Hellriegel also varied the experiment by giving the tubs daily, each evening, as much water as they had lost during the day, thus

maintaining a very constant state of moisture in each. with the following results:

Tub.	Con- stant mois- ture.	Harvest.		Tub.	Con- stant mois- ture.	Harvest.	
		Straw.	Grain.			Straw.	Grain.
	<i>P. ct.</i>				<i>P. ct.</i>		
1	80	11.0	8.8	5	20	6.9	7.7
2	60	12.8	9.9	6	10	3.0	3.8
3	40	11.2	10.5	7	5	0.1	-----
4	30	8.8	8.8				

The general result, therefore, was that the largest harvest is given by soil containing 40 per cent of its maximum capacity for water. The general appearance of the plants showed that those having too little water had a less intensive life and were suffering from lack of nourishment rather than from the want of pure water itself.

Fittbogen (1873) conducted a series of experiments on twenty tubs in groups of four. The relative weights of his harvests of oats were as follows:

Tub.	Mois- ture.	Harvest.		Tub.	Mois- ture.	Harvest.	
		Straw.	Grain.			Straw.	Grain.
	<i>P. ct.</i>				<i>P. ct.</i>		
1	80-60	7.7	6.0	4	30-20	3.7	4.0
2	60-40	6.9	5.3	5	20-10	0.9	0.6
3	40-30	7.7	6.1				

These figures show that for moistures varying between 30 and 80 per cent there was very little difference in the harvest, while for drier soils the harvest was decidedly diminished; but it is notable that for the driest soil (No. 5) the grain ripened earliest of all.

Haberlandt, in 1875, reports the results of experiments on three tubs sown with summer wheat. The quantity of water allowed to tub No. 1 was just sufficient to keep the wheat alive; the other quantities, with the harvest, are given in the following table:

Tub.	Quantity water.	Num- ber wa- ter- ings.	Equiv- alent rain- fall.	Harvest.	
				Grain.	Straw.
	<i>cc.</i>		<i>mm.</i>		
1	6,200	31	24.4	21.8	6.6
2	14,400	36	56.6	29.4	16.4
3	24,800	31	97.5	41.6	31.6

Whence it would seem that the limit of useful water had not yet been reached.

Birner (1881) experimented on the amount of water needed by potatoes. Four series of experiments were made, each including five tubs having different amounts of water, as shown in the following table, which gives the average of the four series:

Tub.	Mois- ture.	Harvest weight of tubers.	
		Per plant.	Aver- age per tuber.
	<i>P. ct.</i>	<i>Grams.</i>	<i>Grams.</i>
1	80-60	809	42
2	60-40	628	46
3	40-30	413	42
4	30-20	313	34
5	20-10	214	23

These figures show a steady increase in the amount of harvest with increasing moisture.

The student will notice that in these experiments where the plants are kept in tubs under protection from natural rains the watering and growth go on under continued sunshine. The experiments therefore correspond with the case of irrigation in a dry, sunny climate, and it is not to be understood that the same amount of water deposited naturally by clouds, with attendant long-continued obstruction of sunlight and heat by the clouds, would have produced the same large crops.

R. Heinrich (1876) experimented at Mecklenburg on the influence of water on grasses and clover. Ten sets of tubs filled with sterile sand were sown with grasses and clover and watered daily, with results as shown in the following table:

Tub.	Weight of daily water.	Equiv- alent daily rainfall.	Harvest weight of fresh- cut grass.	Tub.	Weight of daily water.	Equiv- alent daily rainfall.	Harvest weight of fresh- cut grass.
	<i>Grams.</i>	<i>mm.</i>	<i>Grams.</i>		<i>Grams.</i>	<i>mm.</i>	<i>Grams.</i>
1	100	1	35	6	600	6	138
2	200	2	44	7	700	7	148
3	300	3	57	8	800	8	161
4	400	4	84	9	900	9	156
5	500	5	110	10	1,000	10	170

This shows that the harvest increased steadily up to 8 millimeters of rainfall daily, but for 9 or 10 millimeters per day the increase in harvest was so slight that we may consider 9 millimeters, with an average harvest of 162 grams, as the best that could be obtained under the temperature and sunshine prevailing that year at Mecklenburg. Doubtless a different quantity of water would be required in order to obtain the maximum harvest in other climates.

E. Wollny (1882-83) made seven series of experiments, in each of which five or six tubs received daily different quantities of water, except only that in the driest tubs extra water was given for the first few days in order to insure the sprouting of the seeds, and except, further, that in the experiments of 1882 the water was given every second or third day instead of daily, whereby was brought about the rather large variations in the moisture of the earth. The tubs were shielded from natural rain, were of the same size, and had the same weight of earth and aliment. Nothing is said as to whether special manure or fertilizer was used, but only that all were treated perfectly alike except as to water; the effect of manuring was shown only in the case of Nos. 6 and 7 in that No. 6 was treated like the previous ones, while No. 7 received a supply of mixed Peruvian guano, superphosphate, and sulphate of lime, gypsum, or plaster equivalent to 526 kilograms per hectare. Exact measurements were made upon six plants in each tub in order to judge of the relative harvests. An abstract of Wollny's measures is given in the following tables:

EXPERIMENT OF 1882.

Tub.	Mois- ture.	Grain harvest dried in air.			Mixed grain.
		Sum- mer rye.	Beans.	Sum- mer rape seed.	
1	100-80	4.3	9.2	2.4	11.0
2	80-60	5.7	11.1	4.4	13.9
3	60-40	5.1	11.6	4.9	12.7
4	40-20	3.9	8.3	2.0	9.4
5	20-10	0.4	0.5	0.25	1.8

EXPERIMENT OF 1883.

Tub.	Mois- ture.	Grain harvest dried.		
		Horse bean. <sup>a</sup>	Summerrape seed.	
			Not warmed.	Warmed.
1	100	7.4	0.2	0.8
2	80	21.9	3.3	3.9
3	60	14.0	4.2	4.8
4	40	10.6	4.6	6.9
5	20	3.5	2.5	2.7
6	10	1.3	0.8	1.4

<sup>a</sup>A variety of English or Windsor beans (*Faba vulgaris*) raised in Europe for feeding horses.

He concludes that, in general, the quantity of harvest is influenced to an extraordinary degree by the quantity of available water and much more than by any other factor of vegetation. In general the

harvest increases with increasing water supply up to a definite limit, beyond which the harvest diminishes steadily for any further increase in the water supply, until when the earth is completely saturated with water the harvest in some cases becomes almost nil. The most advantageous percentage of moisture in the soil varies for the different plants, depending on their own method of using the water, on the evaporation from their leaves, and on the number of plants to the unit of area of the field, namely, their closeness to each other.

In reference to the needs of practical agriculture it would be improper to consider in such experiments as these only the water that has been used, since the number of plants to the unit area is of equal if not greater importance. It would therefore be improper to reason from these experiments up to the needs of another field or tub having a greater or less plant density. Again, as also shown by Wollny, more water is used in proportion as more nutriment is available in the ground, because the development of the organs of transpiration or the leaves is thereby increased. Therefore, in general, the quantity of water required to attain the maximum crop will increase with the richness of the soil and the closeness of the plants as well as the dryness and velocity of the wind. For different crops, moreover, the absolute quantity of water will depend upon the duration of the whole process of vegetation, from germination to harvest. (See Wollny, 1881, IV, p. 109.)

The character of the plant affects the quantity of necessary water, not only by the duration of the process, but by the relative quantity of auxiliary organs that the plant develops in order to produce the ripened seed, which we call the harvest. The ratio of the grain to the straw and chaff when the maximum crop of grain is produced in each of Wollny's seven cases is shown in the following table:

*Maximum harvest dried in air.*

	Grain.	Straw and chaff.	Ratio.  <i>P. ct.</i>
I. Summer rye .....	5.7	12.0	48
II. Peas .....	11.6	15.4	75
III. Summer rape seed.....	4.9	7.6	65
IV. Horse bean.....	21.9	31.6	69
V. Colza bean without manure .....	4.6	15.4	30
VI. Colza bean with guano.....	6.9	17.1	40

These percentages show the success with which the plant labors to perpetuate its species with the least possible waste of molecular energy on extraneous matters.

Hellriegel's experiments gave 80 to 60 and sometimes 40 per cent, Fittbogen's gave 40 to 30 per cent, Wollny's gave 80 to 60 per cent of moisture for the maximum harvest. These differences undoubtedly arose, at least in part, from differences in richness of the soil, the closeness of the plants, and differences in the sunshine and wind. These results are therefore in general only relative, and justify us in saying that the best crops are obtainable when the earth contains from 40 to 80 per cent of its maximum capacity for water and that the percentage is higher in proportion as the soil is richer; as the plants are closer; as the leaves of the plants are broader; as the sunshine, the dryness of the air, and the velocity of the wind are greater; and as the barometric pressure is less, since all these increase the useful evaporation from the leaves and the wasteful evaporation from the soil.

The growth of the auxiliary organs was shown by Fittbogen, who gives the weight of the organic matter as determined by burning the well-washed roots, and is also shown by Haberlandt by the weights of the roots and stubble. Their measures are given in the following tables:

FITTBOKEN'S EXPERIMENTS.

Moisture in the soil.	Organic matter lost by burn- ing.
<i>Per cent.</i>	<i>mg.</i>
80-60	470
60-40	429
40-30	440
30-20	359
20-10	109

HABERLANDT'S EXPERIMENTS.

Water.	Weight of roots and stubble.
<i>cc.</i>	<i>Gram.</i>
24,800	5.35
14,400	3.2
6,200	2.9

Again, the variation in the stock independent of the grain is shown by the measurements of the dimensions of the heads and stocks as given in the following tables:

OATS (FITTBOGEN'S EXPERIMENTS).

Mois- ture.	Number of shoots.	Length of heads.	Diame- ter of heads.
<i>Per cent.</i>		<i>mm.</i>	<i>mm.</i>
80-60	8	555	8.9
60-40	8	442	4.1
40-30	4	450	3.6
30-20	2	250	3.8
20-10	4	136	1.4

SUMMER WHEAT (HABERLANDT'S EXPERIMENTS).

Water.	Number of stalks.		Height of stalks bearing heads.	
	Bearing heads.	Not bearing heads.	Shortest.	Longest.
			<i>cm.</i>	<i>cm.</i>
24,800	18	12	70	95
14,400	12	13	80	65
6,200	5	16	20	35

Similar experiments by Sorauer (1873) give results analogous to the preceding. He measured the greatest length and width of the leaves, at several stages of their growth, of barley plants in tubs of different moistures, with the average results for all stages of growth, showing that the leaves were longer and broader the more water was furnished, while the available nutrition remained the same.

BARLEY (SORAUER'S EXPERIMENTS).

Mois- ture.	Length of leaf.	Width of leaf.
<i>Per cent.</i>	<i>mm.</i>	<i>mm.</i>
60	182.2	9.4
40	166.8	9.1
20	138.7	6.8
10	93.7	5.6

These and similar observations show that the assimilating organism of the plant (viz, its leaves), as also its organism for absorbing nutrition (viz, its roots), both alike increase with the increase in available moisture near the roots in the earth, at least within the limits existing in these experiments, and to the same extent is the development of the plant favorable to the increase of its productivity.



Under such circumstances it is not surprising that the development of the crop of grain keeps pace with the increase of the available water, at least up to the point where the quantity of water is sufficient to give a maximum crop.

The supply of water has an influence not merely on the quantity of the crop, but also on the rapidity of the development of the plant. Wollny (1881) shows that in general the grain ripens sooner as the quantity of water diminishes. This is well seen in the following series of experiments (Table 62) on the time of ripening of grain in fields that are sown more or less thickly. The thickly sown fields correspond, of course, to a less quantity of water available for each plant.

WINTER RYE (WOLLNY, 1875-76).

Number of plants to the square meter.	Number of square centimeters to each plant.	Date of ripening (1876).
625	16	July 18
400	25	July 21
229	44	July 28
100	100	July 30
25	400	Aug. 8

PEAS (WOLLNY, 1877).

Number of plants to the square meter.	Number of square centimeters to each plant.	Date of ripening (1877).
357	28	Aug. 15
157	64	Aug. 17
89	118	Aug. 19
85	117	Aug. 26
40	254	Aug. 28
29	346	Sept. 5

POTATOES.

Similar experiments were made by Wollny on the *Ramersdorfer* variety of potatoes. A plat containing 1 plant to 4,435 square centimeters ripened by the end of September (1875), but a plat containing 1 plant to 812 square centimeters ripened the 1st of August, and other plats containing 1 plant to 2,500, 1,600, 1,109 square centimeters, respectively, ripened at dates proportional to the area occupied by each plant. As each plat received the same amount of sunshine and of water, the dates of ripening must have been hastened in proportion as the number of plants in each plat were increased.

**MAIZE.**

Similar experiments on maize showed a similar acceleration of the date of ripening, as given in the following table, which also shows in the last column what proportion of the maize was unripe in the sparsely planted plats when that which was closely planted was already fully ripe.

**MAIZE (WOLLNY, 1875).**

Number of plants to the square meter.	Number of square centimeters to each plant.	Order of ripening.	Percentage of unripe ears.
25	400	1	8.7
16	625	2	0.0
9	1,100	3	23.7
6	1,600	4	84.8
4	2,500	5	56.2

**FLAX.**

A striking illustration of the effect of scant water supply is given in the case of four plats of flax, which were sown at the rate of 50, 100, 150, and 200 grams of seed per 4 square meters of ground. During the drought of 1875 the plants sown most closely all died early in July, whereas those sown most sparsely withstood the drought very well; of the plants sown with intermediate densities the number that died was proportional to the density. In general, if all other conditions are the same, plants ripen sooner and have a shorter duration of vegetation in proportion as the soil is drier, or in proportion as there are more plants to the unit area.

Evidently the plants whose roots extend the farthest in search of water will outlast the species or varieties whose roots are of smaller dimensions.

**RAINFALL AND SUGAR BEETS.**

Briem (1887) has investigated the effect of rainfall on the harvest of sugar beets. His observations were made at the experiment station "Gröbers." A long drought during August and September was followed by a rainy period of many weeks. During the latter the beets increased in weight on an average for each beet from 388 to 450 grams; the presence of sugar was shown by the ordinary polarization test, both before and during the rainy period. The following table gives the results of the analyses, each figure being the average of 16 readings on samples taken from 100 beets. These samples show that immediately after the first rainfall, on September 21, the percentage of sugar per beet diminished somewhat, but that toward the

end of the rainy period, when the rainfalls became less frequent, the percentage rose to nearly its former value. On the other hand there was a regular diminution of the other elements that were not sugar, and consequently an improvement in the percentage of purity. Therefore a permanent injurious influence of the heavy rainfall on the quality of the beet was not proven.

Date of measures.	Num- ber rainy days.	Percentage of—		Quo- tient.	Per- cent- age of not sugar in 100 of sugar.
		Sugar.	Not sugar.		
September 20 (before rain).....	0	13.13	3.27	80.0	24.9
September 27 (after rain).....	6	12.35	3.15	79.6	25.4
October 9 (after rain) .....	9	12.56	2.84	81.5	22.5
October 20 (after rain) .....	3	13.04	2.81	82.3	21.4

Grassmann (1887) also confirms the results of Girard to the effect that the sugar once formed in the beet remains there, no matter what the further growth may be. There the diminution of the percentage of sugar after a rainfall is only relative in that the sugar is dissolved in more sap, and this is distributed throughout a greater mass of beet, the sugar, and with it the percentage of purity, sinks only very little after the first rainy day, but on the second sinks more considerably and then slowly rises from the third to the fifth day. (See Wollny, X, p. 300.)

#### REMARKS.

Now that the previous studies have shown the importance in agriculture of the quantity of available water the question still remains whether the results of these experiments are directly applicable to determining the influence of rainfall on vegetation under the natural climatic conditions. We could in advance answer this question in the negative, inasmuch as the precipitation is never so uniform as the water artificially supplied in these experiments, as also because the utilization of the natural rainfall by the earth varies with the physical properties of the latter; but by a closer consideration one is led to the conclusion that in spite of the departure from natural conditions still the results of these experiments do allow us to draw many conclusions as to the influence of rainfall on the growth of cultivated useful plants, especially when we leave out of consideration the effect of the water at different epochs of vegetation and the peculiarities of the capacity of the soil for water, and at first study only the average character of the climate as depending on the amount of precipitation and consider the weather during the growing season.

In this case it would scarcely be denied that a relatively dry or moist climate or any similar modification of the weather should exert an influence on the vegetation similar to that exerted by the soils of different moistures in the above-described experiments. We must the more readily agree to this conclusion since, independently of the fact that water belongs to the most important, indispensable factor of vegetation, it is also true that the observations on the growth of plants made in climates having different degrees of moisture agree closely with the views above explained. It is already well known in agriculture that in a dry climate the harvests are only scanty and to an extraordinary degree dependent on the rainfall, and, furthermore, it is well known how favorably the general condition of the plants is affected by a moderately moist climate, and how, on the other hand, the crops of cultivated lands are diminished by extremely large quantities of rain, when in consequence of a large capacity of the soil for water, a large quantity of water accumulates in it either temporarily or for long periods of time. Furthermore, it is well known that the stalk of the plants and the formation of straw are greater in proportion as the climate is moister; that the various kinds of cereals in dry regions produce a glassy, glutinous grain, but in moist lands a mealy seed, poor in nitrogenous compounds. All these phenomena, observed on a large scale in the life of the useful plants, make themselves felt also in a similar way in the experiments above quoted, and therefore the results of the latter can with perfect justice be quoted in deciding upon the questions lying at the base of our work. But these present conclusions hold good only for the total rainfall during the growing season, and it will be further necessary to fix in a similar way, by experiments, the influence of precipitation during the individual stages of growth of the plants, as also the relation of the soil to the water, so as to determine the influence of the ordinary natural climatic conditions.

## Chapter VII.

### MISCELLANEOUS RELATIONS.

#### RAPID THAWS.

The following extracts from a report for 1889 of the department of the interior of the Canadian government shows the influence of the change from warm to cold weather not only on forest trees but on other plants:

Considerable attention has been paid to this subject during the past year, and there has been urged on the department of agriculture the desirability of the establishment at some point in the southwestern portion of the Northwest Territories of a farm or garden for conducting experiments on this line. Failure in tree culture so far as tried seems to be owing not to the severity of the winters, nor to the droughts of the summers, but to the winds. Those in the winter known as "chinooks," which cause the sap to rise and the buds to swell, being followed by a lowering of the temperature (in some cases very rapid), prove destructive; and during the summer there are often high, dry, hot winds which blow continuously for several hours and which seem to dry up the young trees. By planting in close clumps the native trees which will grow (cottonwoods and others), and among them those ornamental trees which are so much to be desired, these difficulties will probably be overcome, and in time it will be found what ones are best suited to the district.

The great difficulty which at present impedes the cultivation of large plantations of forest trees in Manitoba and the northwest is climatic. In early spring, delightfully soft, balmy days, something like the maple-sugar weather in Ontario and Quebec, awaken the young trees to life and cause the sap to run; but then suddenly a terrific blizzard from the north and northwest comes down and freezes up the sap and destroys the trees. Professor Saunders is now engaged in experiments with a view to overcoming this climatic obstacle. I have thought that by planting the young trees very closely together, or by sheltering them during their earlier seasons, as is done in the case of the seedlings at the model farm at Ottawa, this trouble might be gradually lessened; or, willows or cottonwood might be planted with the young trees as a shelter-belt protection for them against these early spring frosts and sudden and extreme changes of temperature. As yet, of course, we have no practical experience in the northwest on the subject, and can only base any action we may take upon knowledge obtained from what has been

done in other countries with the same characteristics both of soil and climate. (See American Meteorological Journal, 1891, Vol. VII, p. 41.)

### WIND.

The effect of the wind on vegetation is quite various. Among other influences, we note the following:

(a) It is considered that the mechanical action of the motion of the stems and trunks and stalks is to strengthen them and to stimulate the growth of the roots.

(b) The winds distribute the pollen and the seed and thus assist, or even entirely control, the preservation of the plant and its geographical distribution.

(c) The wind renews the air, so that a superabundance of the necessary gases is then assured.

(d) During cool, clear nights a wind, by renewing the supply of heat, prevents the formation of frosts by radiation.

(e) On dry, cold, frosty nights the wind, by its dryness, evaporates any frost that may be formed upon the plant, but does not prevent the freezing of the plant as a whole.

(f) By bringing moisture, fog, and clouds from the lakes and ocean up over the fields and forests the wind prevents frosts and favors the growth of delicate plants on the leeward side of large masses of water.

(g) Gasparin states that when a cold, dry north wind suddenly blows over plants in active growth they become stunted, and it is said that the plants have taken cold. A similar phenomenon occurs in the valleys of California.

Gasparin's description is as follows (Cours d'Agriculture, 2d ed., 1852, p. 202):

In the valley of the Rhone the north wind produces a lowering of the normal temperature of about  $7^{\circ}$ ; all the vegetation is more or less involved if after several days of calm, clear weather, during which the heat has increased, such lowering of temperature is experienced. Even if there has been no frost and the plants have preserved their vitality unimpaired, it produces a singular effect on them; their growth stops and they remain stunted. Our agriculturists describe this condition by saying that the plants have "taken cold." The leaf buds which put out later resume their growth, but the leaves and branches experiencing this cessation of growth never entirely recover from it. This accident is especially injurious to natural and artificial meadows and to the leaves of the mulberry tree. As regards the meadows, the best thing to do is to hasten the mowing of the grass, in order to gain time for the succeeding crops to prosper, and for the mulberry trees it is advisable to await the development of new buds.

The more rapid these dry winds are the more they hasten the drying up of the soil. After they have prevailed for several days the earth

becomes hard, and this condition prolonged until spring contributes much to injure the growth of the plants. The wheat remains low and does not head; the meadows yield but little grass, if a spell of warm weather does not soon follow so that they may be irrigated, for if the wind is dry and cold at the same time watering will do them little good.

(*h*) Damp warm winds are generally favorable to plants and particularly so to various kinds of fodder. Nevertheless, we observe that under their action the fertilizing proceeds badly, growth is imperfect, and the maturing is retarded.

(*i*) Warm dry winds produce very rapid evaporation, and their effect is still more marked if, like the simoon of Arabia, they carry with them sand heated by the powerful southern sun.

(*j*) Hot dry winds occur, notably along the whole eastern slope of the Rocky Mountain Divide, which by their rapid evaporation use up all the moisture in the plant and in the soil, causing the plant to entirely wilt away.

### **THE ORGANIC DUST OF THE ATMOSPHERE.**

#### **IN GENERAL.**

The dust contained in the atmosphere, in so far as it consists of organic débris, has a slight influence on agriculture, but in so far as it consists of living germs seeking places to rest and grow it is a matter of vital importance. Undoubtedly most of the plant diseases are spread in all directions by the winds that carry the spores of fungi even more widely than they do the seeds of the weeds. But the examination of this dust, either by the microscope or by cultivation in various appropriate moist media, as also the study of the injuries or the good done by the microbes, bacteria, bacilli, micrococci, fungi, and other organisms, belongs to vegetable pathology rather than to the relations between climates and crops and is a subject so large that we must refrain from even attempting to quote the titles of recent treatises on the subject by Pasteur, Miquel, Van Tieghem, Koch, Kohn, and many other prominent authors in Europe and America. Systematic daily examination by the culture method of the dust deposited from the air had been established at Montsouris under Marié-Davy, and at Philadelphia under Dr. J. S. Billings, and will undoubtedly do much to explain the dependence of crop diseases upon wind, moisture, and temperature.

#### **WIND AND FORESTS AND GERMS.**

The influence of the forests on the transportation of the micro-organisms by the wind has been studied by A. Serafini and J. Arata



by counting the collections of organisms that are caught and developed on appropriate glass plates prepared according to the methods of Miquel at Montsouris. Their observations show that in 39 cases out of 40 the catch of germs within the forest is less than the catch outside the forest, the average ratio being as 3 to 1, so that the forests act as a strainer upon the organisms carried by the wind. Wollny suggests that the result would be even still more decided if the wind were stronger and the forests more extensive. (Wollny, *Forschungen*, 1891, XIV, p. 176.)

### **ATMOSPHERIC ELECTRICITY.**

#### **IN GENERAL.**

The relations of atmospheric electricity to vegetation and crops are too little understood to justify any attempt to present this subject. In fact, it does not seem clear that any appreciable influence is exerted by this atmospheric or geophysical element upon the development of plants. In natural conditions evaporation is undoubtedly facilitated by the dissipation of an electric charge, but we do not know that transpiration is at all affected by it, and have no reason to think that assimilation is affected by it. The passage of an electric current through the earth in proximity to the roots may affect the decomposition of the soil and setting free of nutritious substances or may affect the temperature of the soil. A few experiments have been made to show that artificial earth currents stimulate the growth of the plant, but nothing has yet been found to show that under natural conditions electric currents have any appreciable influence. Nevertheless, observations are made regularly at some stations, such as Kew, Montsouris, Potsdam, and at a few agricultural experiment stations.

An excellent series was maintained for many years by Wisliczenus at St. Louis, Mo., a summary of which is published in the transactions of the Academy of Science at St. Louis and also at page 65, Report of the Chief Signal Officer for 1871. The following table gives the monthly means for Montsouris and for St. Louis. The record for Montsouris expresses the potential in units of 1 Daniell cell, which is approximately 1 volt at a point 2 meters above the soil and 1 meter from a wall, for the calm days of the years 1880 to 1887. The record for St. Louis gives the electric intensity on a scale

of arbitrary degrees for a point at the top of a house in that city for all days in the years 1861–1870:

Month.	Electric potential, Mont-souris.	Electric intensity, St. Louis, Mo.	Month.	Electric potential, Mont-souris.	Electric intensity, St. Louis, Mo.
January .....	80	11.0	July .....	36	2.1
February .....	68	9.9	August .....	50	2.8
March .....	49	7.4	September .....	59	2.3
April .....	41	5.6	October .....	65	5.8
May .....	39	4.0	November .....	73	8.0
June .....	39	2.4	December .....	80	8.3

These observations agree with those throughout the world in showing that the intensity is least in the summer seasons and greatest in the winter seasons of the respective hemispheres. There is also a corresponding slight diurnal variation, in accordance with which the intensity at a given point is least at 3 p. m. local mean time.

## **Chapter VIII.**

### **RELATION OF PLANTS TO ATMOSPHERIC NITROGEN.**

#### **IN GENERAL.**

If the atmosphere varied largely in its chemical constituents, this would doubtless have an appreciable influence on vegetation. Laborious studies at Montsouris and elsewhere have shown that there is a measurable variation in the quantity of ozone, so called, of ammonia, and of carbonic acid gas, and Morley, at Cleveland, has shown an appreciable, but very slight, systematic variation in the proportions of nitrogen and oxygen. But all these variations are so small as compared with the variations in the quantity of air brought to the plants by the wind, that their influence on vegetation, if any, can not be separated from that of the wind, and is probably entirely inappreciable as compared with other influences.

On the other hand, the general fact that plants must have nitrogen in order to produce albuminous and other nitrogenous compounds has long been apparent. The question how to furnish this nitrogen to the plants in such a chemical form that it can be readily assimilated by the cells has undoubtedly been, consciously or unconsciously, the problem of the agriculturist for many ages. Without nitrogen, which is usually supposed to be furnished by fertilizers, manures, rich soils, or the alluvial deposits of the rivers, no nutritious seeds are formed, and the more molecules of nitrogen that we can force the plant to take up into its tissues the more and better seed we may expect to obtain in the harvest.

#### **THE AMOUNT OF NITROGEN BROUGHT DOWN BY THE RAIN TO THE SOIL.**

According to Marié-Davy, nitrogen is added to the soil by the natural meteorological process of rainfall. Nitrogen can exist in water either as a dissolved salt of ammonia or as pure ammonia, or in the state of a nitrate or a nitrite of soda or other alkali, or as compounded with carbon, hydrogen, and oxygen, as in the case of organic bodies floating in the water. The nitrogen brought down by the rain water is washed out of the atmosphere where it had existed in some one of these forms, and, although the percentage is small, yet the abso-

lute quantity has an appreciable value as a fertilizer. The methods of determining the quantities of nitrogen need not here be given, but the following results of observations in Europe give at least an approximate idea of the probable effect of rains in the United States. (See *Annuaire de Montsouris*, 1889, p. 254.) Similar data for our own territory have not been measured, so far as I can find.

*Quantity of nitrogenous compounds in the rainfall of 1888 at Montsouris.*

Month.	Total rain- fall.	Num- ber of rainy days.	1 liter of rain contains—		1 square me- ter of ground receives—	
			Am- monia.	Nitric acid.	Am- monia.	Nitric acid.
	mg.		mg.	mg.	mg.	mg.
January .....	21.5	12	5.15	0.84	110.7	18.1
February .....	38.4	13	2.19	1.00	84.1	38.5
March .....	87.7	26	1.51	0.61	132.4	53.3
April .....	55.5	16	1.50	0.78	84.2	43.2
May .....	19.8	7	0.80	0.82	15.8	16.2
June .....	79.6	16	1.10	1.02	87.9	81.2
July .....	76.0	22	0.56	1.36	44.0	103.6
August .....	47.5	11	0.88	1.10	41.7	52.5
September .....	23.0	4	2.33	0.87	53.6	20.1
October .....	19.4	11	2.62	0.68	51.4	13.2
November .....	48.3	17	2.21	0.85	106.7	41.2
December .....	31.6	10	3.62	0.50	114.3	15.9
Total .....	548.3	165			926.8	497.0
Average .....	45.7	14	1.69	0.91	77.2	41.4

*Quantity of nitrogenous compounds in the rainfall during successive years at Montsouris.*

Seasons (warm or cold).	1 square meter receives—		Seasons (warm or cold).	1 square meter receives—	
	Ammo- nia.	Nitric acid.		Ammo- nia.	Nitric acid.
	mg.	mg.		mg.	mg.
1875 (Sept.)-1876 (Feb.) .....	574.9		1883 (Mar.)-1883 (Aug.) .....	431.6	106.4
1876 (Mar.)-1876 (Aug.) .....	499.9		1883 (Sept.)-1884 (Feb.) .....	481.3	228.5
1876 (Sept.)-1877 (Feb.) .....	387.6	210.3	1884 (Mar.)-1884 (Aug.) .....	544.0	91.9
1877 (Mar.)-1877 (Aug.) .....	542.1	135.5	1884 (Sept.)-1885 (Feb.) .....	518.5	152.7
1877 (Sept.)-1878 (Feb.) .....	423.7	93.6	1885 (Mar.)-1885 (Aug.) .....	499.5	152.7
1878 (Mar.)-1878 (Aug.) .....	725.7	50.3	1885 (Sept.)-1886 (Feb.) .....	569.9	137.4
1878 (Sept.)-1879 (Feb.) .....	462.1	169.1	1886 (Mar.)-1886 (Aug.) .....	589.6	222.8
1879 (Mar.)-1879 (Aug.) .....	325.3	285.4	1886 (Sept.)-1887 (Feb.) .....	376.2	158.9
1879 (Sept.)-1880 (Feb.) .....	230.5	336.4	1887 (Mar.)-1887 (Aug.) .....	728.2	219.6
1880 (Mar.)-1880 (Aug.) .....	310.6	299.8	1887 (Sept.)-1888 (Feb.) .....	693.9	180.1
1880 (Sept.)-1881 (Feb.) .....	503.4	264.7	1888 (Mar.)-1888 (Aug.) .....	406.0	350.0
1881 (Mar.)-1881 (Aug.) .....	348.1	181.1	Average, cold seasons ....	508.0	191.2
1881 (Sept.)-1882 (Feb.) .....	415.2	83.4	Average, warm seasons ..	511.7	191.9
1882 (Mar.)-1882 (Aug.) .....	701.5	207.4			
1882 (Sept.)-1883 (Feb.) .....	901.7	279.0			

It is evident that there is no appreciable difference between the warm and cold seasons. A slight addition is to be made to the above table, in order to include the quantities of nitrogen contained in the water of fogs and dew. The quantities under the column "Nitric acid" includes such nitrites as become converted into nitrates in the laboratory analysis. The great variations in the successive seasons depend upon the variations in rainfall quite as much as upon the variations in the quantity of nitrogen per liter, or the variations in the atmospheric constituents.

The variations in the quantity of nitrogen brought to the soil by the rainfall in different parts of the world is shown in the following table, as quoted by Marié-Davy from the memoir of Messrs. Lawes, Gilbert, and Warington, on the composition of the rainfall at Rothamsted. This table shows that the richness of the rain in nitrogenous compounds varies geographically quite as much as the quantity of rain does, so that in general the ground in Germany, Italy, and France receives decidedly more nitrogen per acre than does the ground in England. A further study of the subject also shows that the rain caught in cities contains vastly more nitrogen, especially ammonia, than that caught in the open country.

*Quantity of nitrogen annually brought to the soil by rain.*

Station.	Date.	Total nitrogen—		Station.	Date.	Total nitrogen—	
		Per hectare.	Per acre.			Per hectare.	Per acre.
		<i>Kilos.</i>	<i>Lbs.</i>			<i>Kilos.</i>	<i>Lbs.</i>
Kuschen.....	1864-65	2.08	1.86	Proskau.....	1864-65	28.42	20.91
Do.....	1865-66	2.80	2.50	Florence.....	1870	14.96	13.86
Insterburg.....	1864-65	6.15	5.49	Do.....	1871	11.06	9.89
Do.....	1865-66	7.63	6.81	Do.....	1872	14.01	12.51
Dahme.....	1865	7.46	6.66	Vallombrosa.....	1872	11.63	10.38
Regenwalde.....	1864-65	16.90	15.09	Rothamsted.....	1853-54	6.24	5.96
Do.....	1865-66	11.63	10.38	Do.....	1855	7.29	6.58
Do.....	1866-67	18.41	16.44	Do.....	1856	8.85	8.00
Ida-Marienhutte.....	1865-70	11.12	9.92	Montsouris.....	1876-88	14.04	12.53

The appreciable quantities of nitrogen shown in the above table must be diminished in agricultural computations in proportion as the rainfall carries it off into the rivers, since only that which remains in the soil can be supposed to have an appreciable influence on the growth of crops.

The quantity of nitrates in rain water may be expected to vary with the character of the climate and may be greatest in those regions where lightning is most frequent. Observations on this subject were made by A. Müntz and V. Marcano (*Agr. Sci.*, Vol. III, p. 273), who showed that at Caracas, Venezuela, where thunder storms are fre-

quent and violent, there is a very large amount of nitric acid, either free or combined, in the rain water. The relative values in different climates are as follows:

Locality.	Weight of nitrogen per meter rainfall per hectare.
	<i>Kilos.</i>
The island of Reunion.....	6.98
Caracas .....	5.78
Rothamsted .....	0.83
Liebfrauenberg .....	0.33

#### NITROGEN DIRECTLY ABSORBED BY THE SOIL.

Schloesing has shown that the atmospheric ammonia has its influence upon the plant greatly multiplied by the direct absorption of this ammonia from the air into the soil. The absorption is greatest when the difference between the tension of the ammonia in the soil and that in the atmosphere is at a maximum; it is therefore greatest when the soil is moist and when nitrification converts the ammonia into nitrates as fast as it is absorbed. When the earth is dry nitrification is suspended, and the ammonia accumulates in the soil up to a certain point, beyond which the rate of absorption gradually diminishes. (Agr. Sci., Vol. IV, p. 292.)

#### FIXATION OF NITROGEN BY PLANTS.

Experiments as to the source whence the grains (Gramineæ) and the beans and peas (Leguminosæ) derive their nitrogen have been made both in Germany and France by independent methods. Thus Hellriegel and Wilfarth from 1883 to 1887 experimented upon samples of these plants, each of which was placed in a pot of sterilized quartz sand to which was added a nutrient solution, and the plants were watered with distilled water so as to keep the conditions favorable to growth. The results were that oats and barley behaved alike; when they are not furnished with nitrates there is no development beyond the reserve in the seed, and when they are fed with nitrates the harvest of dry matter is directly proportioned to the quantity of nitrate. For every milligram of nitrogen the increase of dry matter is 93 milligrams for barley and 96 for oats, respectively. Sterilization of the soil and of the pots on the one hand, and the addition of the microbes contained in the washings of cultivated soil on the other hand, cause no variation in the above results.

Peas behave quite differently from the preceding. Some plants languish if they have no nitrates, but others suddenly acquire new

life and yield a crop comparable with that obtained with a good supply of nitrate. The amount of nitrogen in the crop is sometimes a very large gain over that contained in the soil; this latter also occurs when the air is deprived of all ammonia, etc., and the nitrogen must be obtained from the free nitrogen of the atmosphere. But when the soil is sterilized by heat and the pots and seeds are sterilized as to their surfaces by washing with very dilute mercuric chloride, then peas behave like oats and barley; there is no gain of nitrogen from the air, the crops are proportional to the quantity of nitrate in the soil, and no tubercles are formed on the roots.

In all cases where the peas had gained nitrogen when planted in unsterilized soil, tubercles are formed on the roots, and, on the other hand, when they are planted in sterilized soil no tubercles are formed unless we add to the soil the washings of a small quantity of arable soil, in which case tubercles are generally formed. Such washings may themselves be sterilized by boiling or possibly by lower temperatures.

The authors infer that the assimilation of nitrogen from the air by peas, lupines, and other leguminous plants is not within the power of the plant as such; nor can it take place when the plant grows within a sterilized medium, but is connected with the presence of microbes and with the development of tubercles on the roots. (Agr. Sci., Vol. III, p. 215.)

The fixation of nitrogen by Leguminosæ has been studied by E. Bréal, who succeeded in inoculating Spanish beans with bacteria from tubercles on the roots of *Cystisa*. At first the growth was vigorous, then the plant languished, but eventually recovered, flourished, and matured. Again, lucerne, growing in a pot in sandy soil, was inoculated by laying a fragment of tuberculous root of lucerne on the soil and watering the plant with drainage water. In both these cases not only did the plants gain in nitrogen, but the soils also, so that this experiment confirms the ordinary experience as to the behavior of the Leguminosæ as soil improvers. (Agr. Sci., Vol. IV, p. 79.)

Lawes and Gilbert, in a memoir published in the Philosophical Transactions of the Royal Society of London for 1889, state their conclusions as to the sources of the nitrogen in the plant as follows:

In our earlier papers we had concluded that, excepting the small amount of combined nitrogen coming down in rain and the minor aqueous deposits from the atmosphere, the nitrogen source of crops was the stores within the soil and subsoil, whether from previous accumulations or from recent manuring. \* \* \* With the Gramineæ it was concluded that most, if not all, of their nitrogen was taken up as nitric acid. In leguminous crops, in some cases, the whole is taken up as nitric acid, but in other cases the source seemed to be inadequate. \* \* \* It is admitted that existing evidence is insufficient to explain the source of all the nitrogen of the Leguminosæ.



Frank had observed that the feeding roots of certain trees were covered with a fungus, the threads of which forced themselves between the epidermal cells into the root itself; which in such cases had no hairs, but similar bodies were found external to the fungus mantle, which prolonged into threads among the particles of soil. Frank concluded that the chlorophyllous tree acquires its nutriment from the soil through the agency of the fungus. Such a mode of accumulation by these green-leaved plants plainly allies them very closely to fungi themselves; but inasmuch as in the cases observed by Frank the action of the fungi was most marked in the surface layers of soil rich in humus, and since this development has not been observed on the roots of any herbaceous plants, therefore the facts hitherto recorded do not aid us in explaining how the deep and strong rooted Leguminosæ acquire nitrogen from the raw clay subsoils of Rothamsted.

In continuation of their investigations, Lawes and Gilbert have published a subsequent paper stating that in 1888 they began experiments in the same line as those of Hellriegel. Peas, red clover, vetches, blue and yellow lupins, and lucerne were sown in pots, of which there were four to each series. No. 1 contained sterilized coarse white sand; Nos. 2 and 3 contained the same sand, to which a soil extract was added; No. 4 contained garden soil or special lupin soil. Their general results were that the fixation of free nitrogen only occurred under the influence of microbes in the soils that had been seeded with soil organisms by adding soil extract to the sand in the pots. They find that the Rothamsted experiments indicate that with a soil that is rich in nitrates there are far fewer nodules on the roots of the plants than were formed in the pots of sand containing but little nitrates but seeded with soil organisms. The authors suggest (1) that somehow or other the plant is enabled under the condition of symbiotic life to fix free nitrogen of the atmosphere by its leaves, a supposition in favor of which there seems to be no evidence whatever; (2) that the parasite microbe utilizes and fixes free nitrogen and that the nitrogenous compounds formed by it are then taken up by the plant host. On this latter supposition the large gain of nitrogen, as made by the leguminous plant, when growing in a soil that is free from nitrogen but properly infected by microbes, becomes intelligible. (Agr. Sci., Vol. IV, p. 261.)

As to the relations between plants and atmospheric ammonia, almost all agree that the plant derives ammonia from the atmosphere through the medium of the soil only. Berthelot finds that vegetable soils usually have sufficient ammonia to enable them to evolve it into the atmosphere, but under certain conditions they can absorb this gas from the atmosphere. (Agr. Sci., Vol. IV, p. 295.)

Berthelot shows that vegetable soils continually absorb nitrogen from the air, and very much more than exists in the air as ammonia or nitrogenous compounds, so that it must be taken directly from the free nitrogen and this, too, although the soil contains no growing vegetables. (Agr. Sci., Vol. I, p. 120.) Apparently this absorption is the work of the microbes preparing the soil for future plant growth, and much of the irregularity in our crop reports depends not upon the climate or the fertilizer, but upon the activity of this form of life.

Berthelot (1887) shows that the fixation of gaseous nitrogen of the atmosphere by the soil takes place continually even when no vegetation is presented and that it is greater in soil exposed to rain than in soil protected from the rain, this being undoubtedly due to the fact that in the exposed soil the minute forms of life by means of which nitrogenous compounds are formed can operate more intensely because of the greater quantity of air dissolved in and carried down to them by the rain. (See Wollny, X, p. 205.)

A parallel investigation by Heraeus shows that probably the bacteria may be divided into two classes—those which oxidize and those which reduce the oxides, and that in general where an abundance of nutrition exists, as in rich soils, the reducing bacteria are in excess, and that, on the contrary, where these do not find a sufficiently favorable soil there the oxidizing bacteria have the upper hand.

Salkowsky (1887), as the result of his own experiments, considers it indubitably established that process of oxidation in water can only be due to the vital activity of bacteria, and that this is equally true of water permeating the soil, and therefore of the oxidation processes in the soil itself.

Warington (1887), having shown that the process of nitrification goes on by means of organisms that are rather uniformly distributed at the surface, and that they are less frequent at depths of 9 and 18 inches, depending on the porosity of the soil, and that none could be found at depths of from 2 to 8 feet, has now revised these early experiments and finds a few nitrifying bacteria at depths at from 5 to 6 English feet, but that in general they are less numerous and have a feebler activity the deeper they are in the earth. Under natural conditions nitrification occurs principally in the highest layer of soil, because the conditions of this process—viz, accessibility of the air and quantity of nitrogenous compounds—are more favorable here than in the lower strata. (See Wollny, X, p. 211.)

As our views as to the relation of the nitrogen of the atmosphere to vegetation have been entirely remodeled within the past five years, the following summary by Maquenne (1891) has been selected as showing the slow progress of our knowledge up to the brilliant success of Hellriegel and Wilfarth.

Of all the characteristic functions of life nutrition is certainly the most important. It is by means of it and with the assistance of certain inanimate products which we call food that man in the first stages of his existence succeeds in increasing his size to a limit which depends upon his nature and later on succeeds in constantly repairing the loss of material which he suffers in his contact with the outside world.

Nutrition has everywhere the same object, but it may be accomplished in two entirely different ways. In the animal, considered as essentially a producer of power, nutrition is nothing more than a transformation of forces similar to that which we realize artificially in our steam engines. Nourishment must therefore contain within itself the motive power to be used by the organism which absorbs it. In other words, it should be so composed as to be capable of furnishing heat by transforming itself into more simple elements. I speak here of the organic matter which forms, indeed, the basis of nourishment in the entire animal kingdom.

With the plant, on the contrary, which is constantly absorbing energy instead of producing it, the nutriment is no longer subject to any conditions, and thanks to the living force of the solar rays, which the plant stores up in its chlorophyllian tissues, it succeeds in nourishing itself on true products of combustion—such as water, carbonic acid, and nitric acid. In other words, on substances which have reached their maximum stability and which by a concentration of force it converts to the condition of organic matter.

It is thus that the vegetable kingdom has acquired that wonderful power of combination which the methods of our laboratories so rarely attain. It is thus above all that it is able to continually reproduce the combustible matter which the animal kingdom has consumed, and that it enables a limited quantity of matter to suffice for the support of an indefinite number of generations belonging by turns to the two kingdoms.

By its synthetical nature vegetable nutrition must necessarily precede animal nutrition. It is as indispensable to this latter as the light of the sun is absolutely necessary to the development of plants; and this is not, as we may well believe, the least interesting aspect of its study, for it is probable that when we become well acquainted with every detail of the changes which contribute to the organization of mineral matter in the vegetable tissues we shall then be able, by making use of suitable agricultural methods, to assist the nutrition of plants artificially and at the same time to improve our own food, which is the object of all progress in agriculture.

We must also in this connection call attention to the present almost universal use of chemical fertilizers. This is certainly not the only improvement which we have a right to expect from scientific researches, and we shall now see that recent researches relating to the assimilation of liberated nitrates by plants are of a nature to make us look for others and perhaps equally important steps of progress.

Analysis shows that besides some mineral substances whose rôle is still very obscure, the cellular juice of all vegetables is formed of carbon and nitrogen combined with the elements of water—that is to say, with hydrogen and oxygen. These latter are evidently provided by the water which impregnates the earth, and as there is almost always a sufficient quantity of this, we need not occupy ourselves with it here.

Carbon, as we know, is taken by the plants from the carbonic-acid gas of the air, at least for the most part. Carbonic acid, like water, exists everywhere, and if I remind you that we have succeeded in transforming it into some of the sugars which exist so generally in the vegetable tissues, you will agree with me in saying that the great phenomenon of the assimilation of carbon by plants is at present understood only in its smallest details.

The mechanism of the assimilation of nitrogen is far from being as well understood even as that of carbon. We as yet know nothing of the chemical changes which cause this element to pass from a gaseous state to that of albuminous food; but its different modes of penetrating into the plant are well known to us, and we can affirm to-day that the atmosphere contributes as much as the soil to that portion of vegetable nutrition.

This fact, of which we shall shortly give the demonstration, was almost evident, *a priori*. In fact the soil contains only very small proportions of nitrogen. The store which it offers to us (scarcely 10,000 kilograms per hectare) is insignificant in comparison with the immensity of time; but in comparison with it the atmosphere contains an enormous quantity, about three-fourths of its entire volume; hence the idea of a continual circulation of nitrogen between its compounds and the air—in other words, between the air, the earth, and the living organisms—forced itself upon us, in the same way as the circulation of water between the ocean and all points of the earth obtrudes itself.

It is therefore the more remarkable that this conception of the subject has only quite recently been brought to light. Enunciated as a principle more than thirty years ago, it has only been taken into serious consideration in these latter years, after a series of researches which we are now going to pass in review.

But I should like first to establish, by experience alone, outside of all speculative ideas, the fact that the intervention of atmospheric nitrogen in the phenomena of vegetation is an absolute necessity. It will suffice for that purpose that I show a parallel, a sort of balance between the sources of gain and the sources of loss to the soil in nitrogenous compounds; it is clear that if this comparison shows us a difference in favor of the enriching of the soil then we need have no fear of seeing our soil become one day sterile; if, on the contrary, the losses are in excess of the gains from the exterior then we know that it must be receiving from the atmosphere the quantity of gaseous nitrogen equal to the difference. It is very easy to bring together the data for this great problem.

The most important cause of the decrease of nitrogen in the soil is unquestionably the crop taken from it each year; the amount of this loss is, however, very variable; a crop of cereals—of wheat, for example—takes from the soil about 50 kilograms of nitrogen per hectare; roots, beets, or others generally contain more; finally, certain kinds of vegetation, such as clover or lucern grass, take as much as 100 to 200 kilograms, and even more nitrogen per hectare annually.

Judging by these figures, we must conclude that by an average rotation of crops, where root vegetables, leguminous plants, and cereals are made to alternate one with the other, the earth loses every year by the fact of cultivation alone a minimum of from 60 to 70 kilograms of nitrogen in combination with other substances.

On the other hand, the soil is the seat of never-ceasing oxidations, caused by the free circulation of air within it; one of these phenomena of oxidation is that which acts upon the combustible nitrogenous substances held in reserve by the soil; under the simultaneous action of a free atmospheric oxygen and of a special kind of microbe, "the nitric ferment," discovered by Messrs. Schloesing and Müntz and described later by Winogradski, these substances are rapidly transformed into nitrate of calcium, or lime, which, by a happy combination of circumstances, is the favorite nutrition of most plants; this nitrate of calcium is extremely soluble and does not possess any affinity for the elements of the soil, like that existing between these same elements and ammonia, or, again, between them and the salts of potassium, whence it comes to pass that every infiltration of water takes this nitrate along with it, even to the depths of the lower soil, and from thence into the brooks, rivers, and thence into the ocean. In autumn, when the rains are abundant and when the denuded earth evaporates only a small quantity of the water which it receives, a veritable cleansing takes place systematically, and all the nitrates are carried far away as fast as they are produced.

The loss from this cause is enormous. In experiments made by Messrs. Lawes and Gilbert, at Rothamsted, for a great many years past these learned English agronomists have discovered that one hectare of soil planted in wheat loses in this way 50 kilograms of nitrogen—that is to say, as much as the wheat itself contains, or, again, a quantity equal to a manuring of 300 kilograms of nitrate of soda.

These figures are far from being exaggerated, and other observers, among whom I will mention Deherain, have obtained similar and sometimes even higher results than those of Lawes and Gilbert.

But this is not all. Boussingault found that rich soils continually give out ammonia in the gaseous state. These are the circumstances under which he discovered it: Having conceived the idea of analyzing a sample of snow which had remained for thirty-six hours in a garden bed, Boussingault found in it 10 milligrams of nitric ammonia per kilogram, while the same snow taken from a terrace very near there contained scarcely 2 milligrams. The difference of 8 milligrams was evidently due to the emanations from the earth. If we allow that this snow had a uniform depth of 10 centimeters and a mean density of 0.25 we shall find on a hectare a total weight of 250 tons, containing 2 kilograms of ammoniacal nitrogen which was given out from the soil during the short time that the snow lay on the ground.

By what coefficient must we multiply this figure in order to calculate the amount of annual loss which takes place upon an ordinary piece of arable land? We do not know at all, but we can affirm that the result of such a calculation would give more than 10 kilograms annually per hectare.

According to Schloesing, certain soils emit nitrogen in its free, uncombined state. This is particularly perceptible in soils which are badly ventilated and which contain a great deal of organic matter. The nitrogen then results from the decomposition of the nitrates existing in the soil, which decomposition is attributable, as Deherain and I have shown, to the development of certain anærobic micro-organisms.



If we leave out of the calculation this last cause of loss, which it is impossible to estimate and which is doubtless of little importance under ordinary circumstances, we shall find that a piece of arable land of average quality loses, by exhaustion from the crops, the infiltration of rain water and the ammonia which it disengages, an amount of nitrogen equal to a minimum of 120 kilograms per hectare annually. Therefore, as its soil contains scarcely 10,000 kilograms, its exhaustion would be complete in less than a century if these losses were not compensated by gains of about the same extent. Let us now examine into these causes of gain.

The soil receives nitrogen principally by the fertilizers given to it. Their proportion and richness are very variable, but experience shows that in general they do not suffice to supply the loss occasioned by cultivation alone. The difference which is found between the quantity of the nitrogen contained in the crop and that contained in the fertilizers is sometimes very great. Boussingault, to whom we are indebted for very precise researches on this subject, mentions a field where lucerne grass and wheat were cultivated, which having originally received 225 kilograms of nitrogen in the form of manure, furnished in a space of six years 44,000 kilograms of dry hay and 5,550 kilograms of wheat, straw, and grain, containing altogether 1,078 kilograms of nitrogen. The total excess, 854 kilograms, amounts in this case to a little more than 140 kilograms per hectare annually.

In general, this difference is less, but, I repeat, it is always in the same direction and may be estimated on an average at 30 or 40 kilograms annually; it remains then for us to provide for this excess, increased as it is by the losses caused by drainage of nearly 100 kilograms per hectare annually.

The most diverse and sometimes the most improbable reasons have been brought forward to account for this fact. It has even been suggested that the atmospheric dust acted as a natural fertilizing agent; but let us go on to more serious hypotheses. It has been thought that the rain water in taking from the air its soluble compounds might furnish a certain proportion of ammonia or nitric acid to the soil. Analysis has shown that this proportion is extremely small; water caught in a rain gauge contains, indeed, only a mere trace of nitric substances, scarcely 2 grams of ammonia and less than 1 gram of nitric acid per cubic meter, which corresponds to a maximum of 5 to 8 kilograms of nitrogen a year per hectare. This quantity would, then, be barely sufficient to compensate for the losses due to the gaseous ammoniacal emanations from the earth.

On the other hand, Schloesing admits that the earth, and the plants by means of their foliage, directly attract the ammonia existing in the air. This ammonia, according to the learned agronomist, is constantly emitted by the sea water, which thus restores to us under another form the nitrogen which is constantly being brought to it by the drainage water.

It is certain that humid soil can attract the ammoniacal vapors, but it is also certain, as proved by the experiments of Boussingault, that such soil can also emit them; there is, therefore, a tendency to establish, in this respect, an equilibrium between the soil and the atmosphere, the result of which is probably not far from a perfect compensation.

If, then, it is true that the leaves of plants can assimilate gaseous

ammonia, we know that the average air contains extremely few nitric compounds. According to the analyses made first by G. Ville and later by Schloesing, the atmosphere contains at most from 25 to 30 grams of ammonia per cubic kilometer. It would, therefore, be necessary, in order to provide for the loss which we have just spoken of, that the soil and its plants should absorb in the space of a year all the ammonia contained in a column of air having the surface of the field for its base and a height of 400 kilometers under a constant pressure equal to the barometric height at sea level. This is about 50 times the quantity required for the carbonaceous nutrition of a crop weighing when dry 5,000 kilograms.

Such an hypothesis is inadmissible; besides, if it were correct we should not be able to understand why a crop of gramineæ cultivated in a sterile soil, aided only by a small quantity of fertilizer, never contains more nitrogen than was contained in the seed and in the manure given to it.

The above-mentioned deficiency, then, always remains, whichever way we look at it. Let us see if it is real or if the soil receives any compensation.

Since the application of chemical analysis to agricultural researches no decrease in the average fertility of our arable lands has been discovered; on the contrary, many have become richer in consequence in the improvements in the methods of cultivation and, above all, in the regular use of fertilizers. They have therefore become more productive, and the average yield of wheat in France, which, at the beginning of this century, was only at the rate of 11 hectoliters to the hectare, has gradually risen to 15 and 16 hectoliters.

This fact alone is in direct opposition to the hypothesis of a gradual impoverishment of the soil. Here are other objections more striking still:

The forests, the meadows high up on the mountains, which are never manured, have from the remotest ages furnished, in the form of wood, milk, cheese, wool, or viands, quantities of nitrogen inferior, no doubt, to what it would be under a more intense cultivation, but constant and without the soil which produces them showing the least sign of exhaustion.

This virgin soil is even more fertile than our best arable lands. In Auvergne Truchot saw meadow lands containing 9 grams of combined nitrogen per kilogram; Joulie mentions some which contain 1.5 grams, and 1.8 grams per 100 of nitrogen, while land of good quality on which cereals were cultivated yielded ordinarily ten times less. Finally, and it is with this that we terminate this part of our subject, certain plants, among which we must place in the first rank grasses of natural or artificial meadows, cause a progressive enriching of the soil even in the absence of every species of fertilizer, and notwithstanding that they contain more nitrogen than other crops, said to be exhausting, such as the root plants and cereals.

Practical agriculture has long since demonstrated this fact in regard to leguminous plants; all farmers know that wheat planted after a crop of clover or of lucerne grass yields a much better harvest than it would have done under the most copious fertilizing, and it is for this reason they speak of the leguminous plants as ameliorators or natural fertilizers of the soil.



The action of natural meadows in enriching arable soils is of the same nature; here follow some curious results on this subject which I have borrowed from the works of Messrs. Lawes and Gilbert and those of Déhérain.

In 1856 Messrs. Lawes and Gilbert transformed into meadow lands a portion of the domain of Rothamsted, which for a long series of years had been used only for raising grains. The soil contained then 1.52 grams per 1,000 of nitrogen; it was manured regularly and in what would be called excessive doses in such a way that the nitrogen of the fertilizers always exceeded that of the crop by about 15 kilograms every year.

It is evident that they could not pretend with this small surplus to compensate entirely for the losses caused by the drainage; nevertheless the soil, instead of becoming impoverished, was constantly enriched, and at the end of the year 1888 its proportion of nitrogen was 2.35 grams per 1,000—that is to say, 0.83 gram more than at the beginning. This difference corresponds to a total of 1,813 kilograms to the hectare for the entire time that the experiment lasted—that is to say, an annual gain of 50 kilograms per hectare.

The phenomenon is moreover progressive, and nothing in its rate gives any reason for supposing that it is approaching its limit.

At the experiment field of Grignon, my learned instructor, Déhérain, observed similar facts. From 1875 to 1879 he raised beets and maize for fodder upon a piece of land freshly cleared of lucerne grass and containing a proportion of 2.05 per 1,000 of nitrogen. In spite of the fertilizers given to it during that time, the land became rapidly impoverished, no doubt from excessive nitrification, and in 1879 its fertility had declined to 1.50 grams—that is to say, to about three-quarters of its former value.

The maize was then replaced by French grass [*sainfoin*] from 1879 to 1883, then with a meadow of Gramineæ from 1884 to 1888, inclusive, this time, however, without giving it any kind of fertilizer. The soil then began gradually to increase in fertility and has now returned to its former state of richness.

Another experiment very similar to the preceding, but in which they had not manured the soil since 1875, gave nearly identical results.

If we admit that at Grignon the soil of a hectare weighs on an average 4,000 tons, we see that in ten years, from 1879 to 1888, the soil gained under the influence of the prairie grass alone 1,920 kilograms of nitrogen, to which we must add 1,210 kilograms taken away by the crops, or a total of 3,130 kilograms, or more than 300 kilograms a year per hectare.

Here again the limit is far from being attained, and it can be easily understood that soils subjected to this treatment would in time come to contain 10 grams per 1,000, or a hundredth or more of nitrogen, like the meadows mentioned by Messrs. Truchot and Joulie.

It is clear that this natural phenomenon can not be owing to the contributions of nitric compounds brought by the rain water or by the atmosphere, for, even by attributing to these sources a power much beyond that which we have recognized as belonging to them, all plants should then behave in the same manner; whereas we have seen that we must distinguish between the cereals which impoverish the soil continually and the leguminous plants which always enrich it.

Lawes and Gilbert have thought to find an explanation of the ameliorating influence of leguminous plants on the soil in the fact that plants of that kind generally have very long roots and are therefore able to go much deeper in search of their nourishment than the depth at which the roots of the Gramineæ are developed; the enriching of the earth would therefore be due to the organic débris that cultivation leaves there after the harvest, the nitrogen in which had been taken from the subsoil. The defect of this view is that the fertility of the soil decreases rapidly as the depth increases, and in the majority of cases the subsoil contains only such very insignificant quantities of nitrogen that it is impossible to conceive that any plant could be nourished by it, particularly a leguminous plant which contains in its tissues five or six times more nitrogen than does a Gramineæ.

In a word, the most simple observations of practical agriculture show us that the amount of nitrogenous substances furnished by nature would not suffice for the requirements of vegetation; it is therefore indispensable that gaseous nitrogen should interpose directly, and that, too, to an important extent, at least for the cultivation of leguminous plants.

Mr. G. Ville proved this experimentally as early as 1849, and he has not ceased repeating it since then, in spite of the systematic opposition of most physiologists and agronomists.

The primitive experiment of Mr. G. Ville has now become, by recent labors in connection with it, an established fact. Allow me, then, to describe it briefly, dwelling principally upon its results.

In a sterile soil, containing at least 1 kilogram of calcined sand, various leguminous plants, such as peas, beans, lupins, and others, were sown; then were added some nutritive substances, either mineral substances alone or a mixture of mineral fertilizers with a small quantity of nitrate of soda, the object of which was to aid the young plant to pass safely over the critical period of its growth, or, in other words, the time when, having exhausted the alimentary reserves provided for it by its cotyledons, it must henceforth nourish itself with substances entirely inorganic.

The plants were watered with pure water free from ammonia; every precaution was taken to assure the aeration of the soil; finally the plants were kept in as pure an atmosphere as possible, either in a glass cage, where from time to time carbonic-acid gas was introduced, or, what is preferable in the open air, far from the laboratory, and, in general, far from everything which could contribute to the disengagement of ammonia.

Under these conditions, and particularly when the soil received no nitrogenous fertilizer, the plant remained puny at first, suffering from what the German physiologists have called "nitrogen famine." Some plants even do not survive this painful stage of their existence, but die without having sensibly increased their dry weight; others, more vigorous, yield a mediocre crop; finally some, by the side of other dying stalks, become suddenly very flourishing. Upon the first stalk, which up to that time has been lank and without strength, a new stalk seems in some way to graft itself—stronger, stiff, turgescercent—which soon becomes covered with broad, well-developed leaves of a green that are entirely different from the yellowish tint of the

first leaves, and this plant is soon as full of flowers and fruit as if its entire growth had taken place in a soil of excellent quality. The crop is then very good. It contains a large quantity of nitrogen, which evidently could only come to it from the atmosphere.

This recrudescence of vegetation shows itself at a time when the weight of the plant is eight or ten times that of the seed, and similar contrasts are often observed in two stalks grown in the same pot, which are, therefore, consequently in the same soil, under the same conditions, the seeds being as similar as possible.

In a word, the experiments of Ville teach us two unforeseen and equally remarkable facts. The first and most important is that a leguminous plant can live and prosper in a soil entirely destitute of all nitrogenous compounds, thus necessitating the direct assistance of the atmosphere; the second is that all seeds of the same kind are far from behaving in the same manner, whence it results that the course of the experiment is eminently uncertain.

With plants of the family of the Gramineæ nothing similar takes place. The results are absolutely invariable; the crop is zero if the soil does not contain nitrogenous substances. It increases regularly with the quantity of fertilizer, and each seed produces about the same weight of dry material.

The irregularity of the results given by the leguminosæ under the same conditions shows that there could be in this case no question as to the accidental gains of nitrogen, attributable to ammonia or to atmospheric dusts, or to the water used in watering; the fact had been discovered, but its true cause had escaped the discoverer.

G. Ville, convinced of the correctness of the positive results obtained by him, was certainly right in concluding from them that certain kinds of plants attract carbonic-acid gas, but he was not master of his experiment. Other observers also tried to repeat it after him, but did not succeed. Boussingault, in particular, having placed his plants in spaces that were too restricted to allow of the free development of their roots, only obtained stunted plants weighing scarcely four or five times as much as the seed and containing no more nitrogen than the latter, because they had never attained the second stage of their growth.

In consequence Boussingault, who, however, had several years before obtained results similar to those of Ville, thought himself justified in laying down as a principle that vegetables, no matter to what variety they belong, are always incapable of taking even the smallest quantity of nitrogen from the air.

I shall not dwell upon this discussion, which has remained celebrated and which is very much to be regretted, inasmuch as the result of it was that by deterring those students who would have liked to pursue the study of the question further its definitive solution was retarded for thirty years. I only wish here to confine myself to a single point in it, which is that the fixing of free nitrogen by plants was observed already in 1850, with all the characteristics of irregularity belonging to it and as they have been again described in recent physiological researches of German physiologists.

I now come to the recent works, and I shall commence by those of Berthelot, in which we shall be confronted by an entirely new idea—that of the interrelation of microscopic life and the phenomena of vegetable nutrition.

The first experiments of Berthelot date from 1885. Their object was the fixation of nitrogen by denuded soils, leaving out, consequently, all idea of vegetation. The soils used for the purpose were chosen from among the poorest in nitrogen. They were sandy clays taken from Meudon or from Sevres, below the level of the quarries, or, again, porcelain earths, crude kaolins not yet crushed in the mills.

These soils, four in number, were submitted to five series of experiments. They were left to themselves in glazed pots, either within a well-closed room or in the open air in a meadow, either without shelter or under a little glass roof, merely to protect them from vertical rains, or on the top of a tower 29 meters above the ground and without any shelter, or finally, in corked flasks, so as to exclude all possibility of absorption of ammoniacal or nitric vapors. In the fifth series of experiments the same soils had first been exposed to a temperature of  $100^{\circ}$ , so as to destroy from the first all the organic germs that they might contain. The quantity of nitrogen, determined with great precision in each of the samples at the very beginning of the experiment, was again analyzed after two months, and again after remaining five months under the conditions indicated above, allowance being made for exterior additions attributable to air and to the rains when the pots were not sheltered.

The results obtained did not leave the slightest doubt. In every case in which the earth had been left in its normal state it had become enriched, and sometimes to a very great extent more than doubling the quantity of the initial nitrogen; when, on the contrary, the soil had been sterilized by heat, it became constantly more impoverished. In a word, then, poor clayey soils are able to absorb atmospheric nitrogen directly. This absorption is not accompanied by any increase in the previous proportions of ammonia or of nitric acid; it is, then, due to the formation of complex organic substances. Finally, it is the work of a micro-organism, since it ceases to be produced as soon as the soil has been sterilized.

To what sum per hectare does such a fertilization correspond? Berthelot estimates at 20 or 30 kilograms for a thickness of one decimeter of soil. Hence for a thickness of 0.35 meter it would suffice to compensate for the losses inherent to drainage and cultivation; but before going further it is well to remark that the experiments which we have just described relate to particularly poor soils, which are therefore of a nature to enrich themselves. In truly arable soils, averaging from 1 to 2 grams of nitrogen per kilogram, Berthelot has also observed a perceptible fixing of nitrogen, which, however, is relatively less than in sandy clays, and it is probable that this phenomenon would cease to be apparent after a certain limit, which, doubtless, is not very high.

The conditions which, according to Berthelot, appear the most favorable to the fixing of nitrogen by the naked soil are:

1. The presence of a quantity of water comprised between 3 and 15 per cent of total saturation;
2. A sufficient porosity to assure the free penetration of air throughout the whole mass of earth;
3. A temperature of between  $10^{\circ}$  and  $40^{\circ}$  C.

These conditions define the microbe which secretes or fixes the nitrogen as an aerobic organism (i. e., one that feeds on the atmosphere or is aerobiotic).

Except under the conditions previously pointed out, the phenomenon is no longer seen, and, in general, it is limited by the inverse action—that is to say, by a continual dissipation of nitrogen or ammonia into the gaseous state.

Whatever may fix this limit, the fact observed by Berthelot is of the first importance. It is the first time, in fact, that we see the fixation of nitrogen in naked soils clearly stated; especially is it the first time that we see a cause experimentally defined and demonstrated without any reasonable doubt stand forth in the midst of such complex phenomena. This cause, as we have seen, is no other than the development of inferior organisms<sup>a</sup> whose nature it remains for us to define more precisely.

This was an entirely new idea and one which could not fail to produce its fruits. We shall therefore see researches rapidly multiply and lead their authors to more and more definite conclusions.

A. Gautier and Drouin verified first, in artificial soils, the principal results stated by Berthelot; they employed a mixture of siliceous sand, pure limestone, kaolin, and neutral phosphate of potash, to which they added, in particular cases, humus, humic acid or humates, or oxide of iron. This mixture, with the addition of a little nitrate of potassium, seems to be very favorable to the development of leguminous plants.

Under these conditions Gautier and Drouin recognized that the fixation of nitrogen always takes place in mixtures which have received organic matter; in its absence, on the contrary, there is always a loss. Organic matter appears, then, to be an important factor in this great natural phenomenon. It acts, doubtless, by promoting the nutrition of the microbe which fixes the nitrogen.

I will now indicate other experiments, repeated by Ville and Boussingault, in which we shall see the effect of the intervention of vegetation.

Berthelot first undertook a series of cultivations of leguminous plants in large pots which were left in the open air, either with or without shelter, or kept under a glass cover, care being taken to supply the plants with the carbonic acid necessary to their growth.

The soil, the seeds, the gathered plants, the drainage water and rain water were all analyzed with the greatest care in order that an exact comparison might be established between the initial and the final nitrogen.

Under the glass cover the fixation of nitrogen was very weak, because the plant, under these circumstances, did not reach its normal development, but in the open air the quantity of nitrogen fixed was, in every case, superior to that fixed by the soil alone.

For example, the tare tripled this quantity; the crop furnished by a mixture of kidney-vetch and *Medicago lupulina* contained ten times more nitrogen than was contained in the seed bed; a crop of lucerne grass contained sixteen times more, and this excess of nitrogen was always found more abundantly in the roots than in the leafy parts of the plant.

The soil enriched itself, but in a less degree than plant and soil together; therefore active vegetation promotes in an enormous degree

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<sup>a</sup>Aerobies: Micro-organisms which live in contact with the air and require oxygen for their growth. Anaerobies: Micro-organisms which do not require oxygen, but are killed by it.



the assimilation of free nitrogen by the earth, a fact which is in conformity with all observations made in extensive farming operations. The distribution of this nitrogen in the plant shows that it enters through the roots, doubtless in consequence of microbic intervention. Finally, if we sum up the excess of nitrogen thus found in the crop and in the soil, together with the drainage water, we should find, according to Berthelot, 300, 500, and even 700 kilograms per hectare, a part of which evidently remains in the ground as roots, if we are contented to gather only the portion of the crop which is above ground, as is generally done in practical agriculture.

Thus it is that there results the progressive enriching of arable soils under the ameliorating or improving action of leguminous plants; thus also results the possibility of continuous cultivation of certain crops, such as meadow grass or forest trees, without fertilizers and without the earth becoming impoverished.

Joulie arrives at very similar conclusions from experiments of the same kind. The cultivation of buckwheat and of hay on a piece of land in the department of Dombes showed in two years a fixation of nitrogen equal to more than 1,000 kilograms per hectare. The mean of twelve experiments, one only of which showed a loss of 0.0136 gram per 1.5 kilograms of soil, showed a fixation of about 500 kilograms of nitrogen per hectare in a space of two years.

A little later Messrs. Gautier and Drouin also found, under the influence of the cultivation of common beans, an enrichment of their artificial soils which, as they estimated, corresponded to 185 kilograms per hectare for a single crop only.

Finally Pagnoul, after having recognized that the soil alone is capable of directly fixing the nitrogen of the air, found like the preceding authorities that the enrichment of the soil took place to a considerable extent even with a simple crop of grass or clover. For the latter he found fixations amounting to 500 and 900 kilograms of nitrogen per hectare.

We see that all these results are in absolute accord with each other, and, what is worthy of remark, they are of the same order of magnitude in experiments made by several different persons. Nothing is wanting to them but the direct control to be obtained by a change in the composition of the gases in which the plants grow.

From this point of view the experiment is particularly difficult to carry out. The plants must be kept constantly in closed vases in a confined atmosphere, consequently in the presence of vapor of water at its maximum intensity, which seems to be an eminently unfavorable condition; besides, it is necessary to be able to measure the volumes of the gas contained in the apparatus, to analyze them with scrupulous exactitude, and, finally, to promote the chylrophyllic nutrition by regular additions of carbonic acid without allowing the proportion of oxygen to vary too greatly. Schloesing, jr., and Laurent have triumphantly overcome all these difficulties. In a memoir published in 1890 these clever experimentalists state that in the space of three months three seeds of dwarf peas sown in a soil destitute of nitrogen, but prepared in such a manner that the absorption of nitrogen could easily take place, absorbed from 26 to 29 cubic centimeters of nitrogen, weighing 32.5 milligrams and 36.5 milligrams, respectively. This nitrogen, measured volumetrically, was found again (with all the precision requisite in so delicate a research) partly in the soil,

which was enriched on an average to 12 milligrams, partly in the plants, which had gained 20 to 30 milligrams, although, owing to the narrow space in which they were confined, they were not able to attain their full development.

This last proof appears to have finally closed the discussion formerly inaugurated by Boussingault and which had not been completely closed by the analytic results explained above.

Thus a few years have sufficed to definitely decide this theory of a direct assimilation of nitrogen by plants, first enunciated by Ville.

What, now, is the mechanism or *modus operandi* of this assimilation? We have just seen how Berthelot was led, by certain peculiarities of his experiments, and, above all, by the complete cessation of all fixation of nitrogen in soils that had been subjected to a temperature of  $100^{\circ}$ , to admit that nitrogen is assimilated directly by certain inferior organisms which force it into organic combination; but we have also seen that the fixation of nitrogen by naked soils is always weak and generally insufficient for the necessities of a normal vegetation.

It is true that when the aid of a leguminous plant is invoked the fixation becomes more active and may become powerful enough to compensate alone for all the known causes of loss; but how, then, are we to account for the difference in this respect found between the *Leguminosæ* and the *Gramineæ*? Shall we be forced to admit that the *Leguminosæ* are able, by themselves, to assimilate gaseous nitrogen, by a power possessed by them which is wanting in the other species?

Berthelot has concluded, from his researches upon this subject, that in the development of leguminous plants there comes into play some micro-organism which facilitates the fixation of nitrogen upon the root of the plant, or rather upon the mass formed by the root and the soil, intimately connected one to the other; but this idea could not be definitely adopted unless the existence of such a microbe were proved by experiments. This result is fully demonstrated by a series of very remarkable experiments made by Hellriegel, Wilfarth, Frank, Prazmowski, and others in Germany, and which have been most successfully verified by Bréal, Schloesing, jr., and Laurent in France, and, finally, by Lawes and Gilbert in England.

Before proceeding to explain these researches I must call attention to a well-established fact which had been well known for a great many years, although no one before Hellriegel and Wilfarth ever thought of seeing in it anything more than a phenomenon of nature.

When we examine the roots of a leguminous plant grown in good soil we always see irregularly disposed on them tuberculous enlargements, a kind of nodosity [node, nodule, knot, or knob] formed of a special tissue and apparently quite accidental. Examined with a microscope the interior of these excrescences appears to be filled with corpuscles of varying forms, always animated with the "Brownian" movement, although they have sometimes a movement of their own. These assume various shapes; sometimes they are like simple rods similar in form to certain bacteria; sometimes they have the appearance of vegetable coralloids and take the branched T or Y form more or less ramified.

Botanists have for a long time discussed the nature of these excrescences, but at present it seems to be generally admitted that, morpho-



logically considered, they constitute roots modified by the penetration of an exterior organism. Under no circumstances have we a right to consider them as a natural production of the plant, because, as Prazmoffski has shown, plants that are kept protected from all causes of contamination are always free from them; while, on the contrary, their roots become covered with a multitude of nodosities when plunged into a liquid where a tubercle has been crushed or when they are replanted in any sort of soil that is watered with a similar liquid.

The artificial infection of the roots of leguminous plants, as enunciated a dozen years ago by Prillieux, has been verified by Hellriegel and Wilfarth, Prazmoffski, Laurent, and Bréal. This latter investigator has even discovered that we may certainly assure the formation of a tubercle by pricking the root of a leguminous plant with a needle which had been previously inserted into a tubercle growing on another root.

There remains no doubt of this fact: The nodules of the Leguminosæ have a microbial origin. The organism which causes them has received the name *Bacillus radicicola*; Laurent places it beside the *Pasteuria ramosa*, between bacteria proper and the lower fungi. Essentially aerobic in its nature, it resists all freezing and drying; but a temperature of 70° C. is sufficient to destroy it. It has been successfully cultivated in bouillons made of peas, or of beans, supplemented with gelatine and asparagine, or even in a solution of phosphate of potash and of sulphate of magnesia, to which is added a little sugar, but without any nitrogenous substance whatever. This organism grows in such liquids, preserving its habitual ramified forms, but without producing any true spores.

As to the tubercles themselves, they have until lately been considered as morbid productions, useless to the plant. Some authors have sought to see in them organs either of reserve or organs for the transformation of the albuminous substances necessary for the nutrition of the plant; others—and this is the general opinion at the present time—look upon them as the result of a symbiosis—that is to say, of an extremely intimate association between the root of the plant and the microbe living with it, entirely different, however, from the action of the ordinary parasite.

Hellriegel and Wilfarth were the first to discover a connection between the development of bacteroidal nodosities and the assimilation of gaseous nitrogen by the Leguminosæ. After having observed that in a culture of peas the most vigorous plants were always those that possessed the greatest number of tubercles, these investigators carried out many series of systematic experiments in glass jars containing 4 kilograms of quartz sand, to which they added certain of the principal minerals necessary to vegetation, such as phosphoric acid, sulphuric acid, chlorine, potassium, etc., and in certain cases a small quantity of nitrogen in the form of nitrates.

In these jars, which were exposed to the open air, they sowed barley, oats, and peas. The results were exactly the same as those formerly obtained by Ville and Boussingault.

In soils destitute of nitrogen the crop of cereals (barley and oats) is nearly nil, but it increases in approximate proportion to the dose of nitrate added, so that for each added milligram of nitrogen there is an increase of crop equal, on an average, to 95 milligrams of vege-

table matter. Thus we see that all the experiments agree with each other.

In the case of peas the results are entirely different, for we see, as in Ville's former experiments, that by the side of a plant weighing less than a gram there will be another plant weighing 10 or 15 or 20 grams, and even more, without its being possible to attribute the difference to any apparent influence coming from the outside. There is a régime of absolute irregularity, and an examination of the roots shows that the irregularity is proportional to the presence or absence of tubercles on the roots, whence arises the connection above mentioned.

It now only remains for us to distinguish between cause and effect. Is this appearance of these nodosities in itself merely a consequence of the greater vigor of the plants, or ought we, on the contrary, to see in these very tubercles the origin and cause of that greater vigor? The following experiment will show us which of these two hypotheses is correct:

When to the same soil of sterile sand which served for the preceding experiments only 5 grams of good arable soil dissolved in 25 cubic centimeters of water was added, the peas grew in a natural manner and produced, on the average, from 15 to 20 grains of dried crop. Each stalk contained, on an average, 450 milligrams of nitrogen, although there were scarcely 10 contained in the soil. In every case there was a fixation of nitrogen in the gaseous state amounting to nearly half a gram.

Under the same conditions a seed of lupin produced a crop of from 42 to 45 grams, containing more than 1 gram of nitrogen.

French grass (*sainfoin*) produced the same results, and in all cases we see that the roots of these different plants are abundantly provided with tubercles; but if the artificial soils and the solutions of earth employed in these experiments have been sterilized by the action of heat the plants remain invariably puny and produce less than 5 grams of dried material per stalk. In this case the tubercles are always wanting.

Under cover, in pure air to which a little carbonic-acid gas has been added, the results are a little less favorable than in the open air, but they still show an important fixation of nitrogen in the case of *Leguminosæ* infected with bacteria.

These principles, then, represent the determining cause of the phenomenon, and the systematic addition to the soil of appropriate germs will enable us hereafter to reproduce at will the experiment of Ville, which was formerly attended with such uncertain results.

In the Museum of Natural History, Bréal has obtained results similar to those of Hellriegel and Wilfarth. In one of his experiments a pea containing 9 milligrams of nitrogen, in a soil of poor gravel, but into which bacteria had been sown, produced a plant weighing 103 grams in a green state, 32.3 grams when dried, and containing 358 milligrams of nitrogen—that is to say, 40 times as much as the seed. The pea vine, which was 1.40 meters long, produced 14 ripe pods; the gain in nitrogen thus realized corresponds to about 255 kilograms per hectare.

In another experiment, a small plant of lucerne grass provided with tubercles and weighing 10 grams, and likewise in a soil of sterile sand, gave a crop weighing 332 grams when green, 85.5 when

dried, and containing 1.733 grams of nitrogen. The total fixation of nitrogen amounted to 1.715 grams for the surface of the flowerpot, or 274 kilograms per hectare.

It is a remarkable fact that before the formation of the fruit the nitrogen in the Leguminosæ is, by preference, localized in their roots. This fact is due to the great richness of the tubercles with which they are covered. Bréal found in the nodules of several plants, such as kidney beans, peas, lupins, lentils, acacia, etc., as much as 7 parts of nitrogen to a hundred of dried material, even when the fibers of the roots never contained more than 2.5.

Another fact, not less interesting, brought to light at the same time by the experiments of Hellriegel and Wilfarth, is the difference shown by arable soils in their capacity to initiate the appearance of tubercles upon the roots of leguminous plants. Some of them are very efficient in this respect; others are much less so. There are even some soils which are more favorable to the production of tubercles in certain species of plants than in others. This is a fact very difficult of explanation, for the solution of which further and bacteriological researches will be necessary, because variations of this kind can only be due to a difference in the microbe itself, the penetration of which into the roots produces these nodules.

In the experiments of Hellriegel and Wilfarth the sowings were made with the washings from earth, containing, as we know, a multitude of micro-organisms having different functions. Some of them, it is true, were made with a liquid containing a little of the white substance which comes from the nodules when they are crushed, but all precautions had not been made to get rid of the germs which the water itself might have contained, or which might have been brought either by the young plant or by the atmospheric dusts.

It was therefore necessary in order to be sure that the fixation of the nitrogen was really due solely to the bacteria of the nodule to repeat the preceding experiments with all the precautions required by microbic researches.

This work of revision was carried out with scientific rigor by Prazmoffski, in Cracow, with great success.

The vessels used for growing the plants were provided with a cover, which fitted tightly and had four holes pierced in it. One of these holes, made in the center, permitted the young plant to pass through it. The three others allowed of watering and of the passage of a current of pure air. All these holes were closed with plugs made of a sterile wadding, which prevented the entrance of all germs of exterior organisms.

The soil was formed of about 3,500 grams of siliceous sand, previously washed in boiling hydrochloric acid, then in water, and finally heated red hot. Pure mineral fertilizers without any nitrogen whatever were then added to it.

The whole mass was then sterilized by being heated for at least two hours from 140° to 150° C.

In these vessels peas which had been previously sterilized were sown. To effect this they were first plunged into a solution of corrosive sublimate, then washed in alcohol, which latter was finally set on fire and burned upon the seed itself.

Some of the vessels received also bacteroidal germs contained in a nonnitrogenized bouillon culture liquid.

But in spite of all of these precautions it was not always possible to prevent the penetration of foreign organisms to the tubercles. In a certain number, however, of the successful experiments in which the bacteria alone remained in contact with the roots the results obtained were identical with those obtained by Hellriegel and Wilfarth. There was a fixation of nitrogen in all the pots in which the bacteria were sowed, and in those only.

Thus in a sterile soil, without microbes, a pea containing 12 milligrams of nitrogen produced only 1.166 grams of dried crop, in which 13.2 milligrams of nitrogen were found, or about as much as was contained in the seeds sown. Where microbes were present, on the contrary, the dried crop weighed 3.544 grams and contained 82.6 milligrams of nitrogen. Therefore the bacteria had given to the plant the faculty of taking from the air 70 milligrams of nitrogen independently of all other microbic intervention and under the same exterior conditions.

By using water in the place of sand Prazmoffski also obtained the same results. Some peas grown in a nutrient solution without nitrogen and sterilized gave only 9 milligrams of nitrogen, whereas others grown in a similar liquid but supplied with bacteria gave from 26 to 82 milligrams.

These experiments then verify in the most complete manner the views of Hellriegel and Wilfarth; the fixation of nitrogen by the leguminosæ is a consequence of their symbiotic union with an infinitely small organism whose germs are profusely scattered abroad and which enables these plants to grow sometimes with vigor without any artificial inoculation in soils destitute of all nitrogenous food.

It was these germs which enabled G. Ville to first observe the fixation of atmospheric nitrogen by these same plants, and it was their irregular dissemination which caused the inequality in his experiments, and if Boussingault found it impossible to obtain the same results it was simply because he cultivated his plants under such conditions that they could not acquire sufficient vitality to profit by their union with these bacteroids.

In effect at the beginning of vegetation in soils without nitrogen, but into which microbes have been introduced, an interval of stoppage of growth has been observed, so complete as to make us fear a rapid decay of the plant, and this period of intermission always coincides with the appearance of the tubercles on the roots of the plants. At this time the invading organisms derive their nourishment from the juices of the young plant; they exhaust it, and if the latter has not the strength to resist this invasion, which then constitutes a sort of parasitism, if its roots are not able to develop freely, or, again, if its leaves remain in a badly ventilated atmosphere, always saturated with aqueous vapor, the plant will inevitably perish.

If, on the contrary, it can resist, it will very soon gain the advantage; it then takes from the bacteria the nitrogenous matter which they contain and compels them to form more of it from the nitrogen which surrounds them. Doubtless on its side the bacteriod profits as much as the plant from its symbiosis; it is probable that it receives from the latter hydrocarbons—sugars or others—in exchange for the albuminoids which it gives to the plant, and thus it is that this union may exist until, finally, the moment arrives when the plant, having

attained its full growth, entirely consumes the tubercles in order to assimilate them and thus form its seed.

It is then, in short, by means of their roots that the leguminosæ draw the nitrogen from the air, and this conclusion agrees with the well-known fact that a living leaf is incapable of modifying the volume of nitrogen into which it may be plunged, and that it is the root which in the first stage of vegetation always shows the greatest richness in nitrogen.

It is the remains of these roots and the rupture of the tubercles that are carried on them which determine the enrichment of the soils of meadows, and the dispersion of the germs of the microbe that fixes the nitrogen.

It has been objected to the conclusions of Hellriegel and Wilfarth that up to the present time it has been impossible to observe a fixing of nitrogen by the bacteroids alone independently of their symbiotic alliance with a leguminous plant. This is true, but it must be remembered that the obtaining of such proof is fraught with great experimental difficulties; the micro-organism, cultivated, we will suppose in a place where there is no nitrogen, will certainly take the nitrogen from the air, but not more than is necessary for the formation of its tissues; that is to say, an extremely minute quantity, for the microbe itself weighs very little, and thus it happens necessarily that the phenomenon remains undetected by even the most delicate methods of analysis.

In order that the absorption may be manifest it would be necessary that we should be able, as the Leguminosæ actually are, to take from the bacteroids their nitrogenous substance as fast as it is produced, or that it should be cultivated in such quantities that the dry weight should attain measurable quantity. Shall we ever discover the means of making this experiment? It is impossible to say at this moment, but what we can affirm is that it is not correct to conclude, as certain authorities have done, that the bacteroids are incapable of fixing nitrogen gas when alone, basing their objections solely on the ground that up to the present moment it has not been possible to prove such a fixation of nitrogen.

Besides, atmospheric nitrogen is but a part of the complete nourishment of the Leguminosæ; since, in common with other species of plants, they can assimilate the nitrates and ammoniacal salts, although in a less degree.

When a pea, a bean, or a lupin grows in a fertile soil it never shows that tendency to perish due to a "famine of nitrogen," which characterizes the same plants in a sterile soil; the plant's vitality is great at the beginning of its growth and it is for this reason that, in order to insure the success of his experiment, G. Ville advised that a small quantity of nitrogenous fertilizer be added to the mineral substances that are given to the sand in which the plants were cultivated; in this case, however, the tubercles are less abundant and the sum total of the nitrogen borrowed from the atmosphere is lower.

If this bacteroidal action be not the only one capable of furnishing to leguminous plants the nitrogen necessary to them, there is evidently no occasion to draw an absolute line of demarcation between these plants and others, which being less qualified to associate themselves with the microbes (doubtless because the medium that these offer to them is less favorable to their development) derive, therefore,



more benefit from nitrogenous fertilizers. Between the Papilionaceæ and the cereals, which occupy extreme positions in regard to the capacity for fixing atmospheric nitrogen, there exist probably other intermediate species capable of exercising the same function in every degree. These latter must be less improving to the soil than the Leguminosæ, but they must assuredly be less exhausting than wheat, Indian corn, or beets, and it is impossible to explain otherwise than by reasons of this kind the continued growth of forests and meadows which continue incessantly to furnish crops in soils which never cease to be much richer than our cereal soils, although they never receive any fertilizers.

According to Ville, the Cruciferæ in particular are capable of taking a part of their nitrogen directly from the air. On the other hand, we know that the roots of certain species of forest trees form a symbiosis with some kinds of mushrooms which are not yet well known and which perhaps act in the same way as the bacteroids of the nodules. I shall not, however, insist upon facts which are liable to discussion and which require to be studied more minutely and with all the care which has been bestowed upon the study of the Leguminosæ.

I have now only one more point to examine in regard to this question, a point which, although still involved in obscurity, is nevertheless very interesting. All planters are well aware of the fact that a leguminous plant can only be grown for a few years in the same soil. After being very flourishing for a short time a field of clover or of lucerne dwindles away, the crops rapidly become less abundant, and finally the soil is invaded by the Gramineæ, which rapidly transform the artificial meadow into a natural one, unless precautions have been taken, by clearing the land, to prevent the phenomenon. To what can we attribute this spontaneous transformation? The microbe has had at its disposal all the elements necessary for its growth and its dissemination. Why does it cease all of a sudden to exercise its favorable influence? Perhaps there is in this something very important, which I can, however, only express in the form of an hypothesis, but which, nevertheless, I think is worthy of having your attention called to it. Pasteur has shown us that certain inferior organisms change their nature, lose their noxiousness, or become more virulent if they are made to pass from one species of animal to another. May it not be that the bacterium of the nodules undergoes also a modification by its prolonged contact with the roots of the Leguminosæ and that it would be necessary for it, in order to resume its former functions, to pass to some other species of plants—in other words, to change its surroundings? Experience alone will solve this question. I will content myself here with putting it before you.

Scientific researches sooner or later always find their practical applications; these that I have had the honor of bringing before you can not fail to render important services to agriculture. The "restoring" part played by the Leguminosæ is known to all agriculturists; it has become an axiom of agriculture and forms the basis for the rotation of all crops; but after the experiments which we have just passed in review it assumes for us a strictly scientific character which it did not possess before. The *modus operandi* of the process has been determined, and by a simple modification of the processes of cultivation now in use, by assigning a still more extended

sphere to leguminous plants, it will be easy for us to profit by this newly acquired knowledge in order better than before to preserve our lands in a state of suitable fertility. Suppose, for example, that clover, let us say, has been sown with any cereal and that it is left to grow freely, after the harvest; this clover will take a certain quantity of nitrogen from the air, by the help of the nodules on its roots. If this clover is plowed under before the next time of sowing, in the spring or autumn, so as to serve as a green fertilizer, we shall have obtained, with no other expense than the price of the seed, a manure derived wholly from the air of the atmosphere.

This practice, first recommended by Ville, has been recently shown by Deherain to have another advantage quite as important. By keeping the surface of the soil in a state of constant evaporation the interpolated cultivation of the clover diminishes the drainage to a notable extent; all the nitrates, which then are formed in large quantities and which would be lost if the earth remained uncovered, are held and assimilated, being rendered insoluble by the vegetation, and when plowed under will augment by so much the more the natural reserves of the soil.

This method, whether we consider it as the cultivation of a fallow field or whether we call it "sidération,"<sup>a</sup> as proposed by Ville, affords two advantages of primary importance—it prevents in a great measure the losses due to excessive nitrification of the soil in autumn, and restores to the earth a certain quantity of nitrogen which has passed from a gaseous state to the state of organic matter. I do not think it an exaggeration when I say that the gain from this practice alone is equivalent to a strong artificial manuring of the soil, and it may sometimes even attain a value of many hundred francs per hectare, which will be realized in subsequent crops.

Finally, among other examples of the application of this new knowledge there is a most curious fact which has just been pointed out by Salfeld, in Germany, and which, if proved, will be a further confirmation of the immortal doctrines of Pasteur. After clearing a peat bog situated on the banks of the Ems, on the frontier of Holland, horse beans and vetches were sown. The soil was everywhere enriched with mineral fertilizers, but on one part only of the field a small quantity of good arable earth was spread, in the proportion of about 40 kilograms to the are.<sup>b</sup>

The effect of the addition of this latter element was, as it appears, most surprising; under its influence the crop was doubled. This result is, in Salfeld's opinion, similar to the results obtained by Hellriegel and Wilfarth in their laboratory experiments; if this is really so—and it is possible—there will be in the near future a new era, a sort of revolution, so to speak, in practical agriculture.

Perhaps the time is not far distant when our farmers will add to the fertilizers of commerce [the so-called soil improvers and complete manures, etc.—C. A.] true culture broths, prepared according to the methods in use in microbic researches, and which will furnish to plants the germs of organisms capable of fixing nitrogen [the nitrogen fixers], or, perhaps, others still, favorable also to their develop-

<sup>a</sup> This medical term for atrophy or mortification does not seem quite appropriate in this case.—C. A.

<sup>b</sup> The are is about 119 square yards, or 100 square meters, or 1,071 square feet.



ment and which will cause their crops continually to increase and will finally enrich the soil to the extreme limit of its possible fertility.

This would undoubtedly be a vast extension of that admirable humanitarian work for which we are indebted to Pasteur; but this is anticipation, and I only proposed in this lecture to point out the present state of the question. I shall therefore close by summing up what I have said in a few words.

Experiments made by Ville, and repeated and verified by many other observers, have shown us that certain plants, particularly those of the species of the Leguminosæ, have taken from the atmosphere a part of the nitrogen that they contain.

Berthelot, and also Gautier and Drouin, have shown that the soil alone can to a slight extent enrich itself by means also of a direct fixation of gaseous nitrogen.

Berthelot has also shown that this phenomenon corresponds with the development of certain microbes preexisting in the soil; and, finally, Hellriegel and Wilfarth have discovered this micro-organism in the nodules on the roots of the Leguminosæ.

This last work is certainly one of the greatest interest, and does the greatest honor to the physiologists who have succeeded in bringing it to a final result; but it is proper to recognize that the route to be followed had already been marked out by previous researches. The problem was ripe for solution, and it was in our own country—in France—that the great problem of the assimilation of nitrogen had been proposed and in a great part solved, which is no more than was to be expected from so great a center of production and agricultural progress.

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Professor Frank, of the agricultural institute in Berlin, finds that the tubercles may be removed from the plant without stopping the process of taking nitrogen from the air. Evidently, therefore, the subject has to be investigated still further. (Agr. Sci., Vol. IV, p. 68.)

Frank has also shown that the symbiosis in the tubercles of the Leguminosæ is of an entirely different character from that which occurs in the roots of any other plants. Furthermore, when the soil is rich in humus the microbic parasite does no special service to the host, but when the supply of humus is insufficient the microbe symbiont is of the greatest service to the host. (Agr. Sci., Vol. IV, p. 266.)

H. J. Wheeler, of the Rhode Island Experiment Station, gives (Agr. Sci., Vol. IV, p. 55) an account of the work done by Professor Hellriegel at Bernburg, Germany, along the line of investigation conducted by Boussingault and Ville in France, Lawes and Gilbert in England, and W. O. Atwater, of the Storrs School Agricultural Experiment Station. In the present state of the question it may be considered as settled that certain plants are able, if supplied with all the other essential elements, to draw their supply of nitrogen from

the air, either directly or indirectly, by means of minute organisms now generally termed microbes. These microbes can be communicated by direct inoculation from one plant to another that has been previously free from them. Experiments are in progress as to the possibility of cultivating these microbes artificially, and when this has been accomplished successfully it will mark a great step toward the solution of the question as to the plant's method of obtaining nitrogen, and not only that, but a great step toward success in agriculture, since every one will be able to inoculate his own plants, and thus immensely stimulate the yield of crops.

T. Leone has shown that a great number of germs obtain their nitrogen more easily by decomposing the nitrates, and only when these salts are used up do they begin to nitrify the ammoniacal compounds, and after that possibly attack the free nitrogen of the air. He has also shown that these take the nitrogen as a gas from the nitric acid in the nitrates and do not convert it into ammonia. (Agr. Sci., Vol. V, p. 82.)

Leone also shows that the phenomena of nitrification and denitrification occur alternately according to the relative amount of nutrient and number of bacteria present in the water. The manuring of soil, therefore, gives rise to a cycle of phenomena, nitrification being first arrested and the nitrates and nitrites reduced until a maximum formation of ammonia is attained, when nitrification again commences. The destruction of the nitrates and nitrites in the soil is complete or partial according as the supply of manure is abundant or otherwise. (Agr. Sci., Vol. V, p. 107.)

The experiments made in Europe by Boussingault, Hellriegel, and others as to the method by which plants obtain the nitrogen from the atmosphere have been repeated and extended by C. D. Woods, of the Storrs School Agricultural Experiment Station. His results are summarized as follows:

(1) Peas, alfalfa, serradella, lupine, probably clover, and apparently all leguminous plants, have the power of acquiring large quantities of nitrogen directly from the air during their growth. There is no doubt that the free nitrogen of the air is thus acquired by these plants. This acquisition has something to do with the tubercles on the roots of these plants, but the details of the process are still to be solved. The cereals, oats, etc., with which experiments have been brought to completion, do not have this power of acquiring nitrogen from the air, nor do they have such tubercles as are formed on the roots of the legumes. They get their nitrogen from the nitrates or nitrogenous fertilizers. The tubercles on the roots of the legumes may be formed either after or entirely without the addition of solutions or infusions containing micro-organisms, and a plausible supposition is that when such infusions are not furnished the spores of the organisms were

floating in the air and were deposited in the pots in which the plants grew. As a rule, the greater the abundance of tubercles the more vigorous were the plants and the greater the gain in nitrogen. The gain of nitrogen from the air by the legumes explains why they act as renovating crops. (Agr. Sci., Vol. IV, p. 22.)

From some careful experiments by A. Petermann on yellow lupins (*Lupinus luteus*) the author concludes that the physiological rôle of the tubercles must not be exaggerated. They can not be the only cause of the fixation of nitrogen, although their presence may explain why the intervention of atmospheric nitrogen is most marked in the case of the Leguminosæ. He further shows that sodium nitrate is not injurious, but beneficial, to lupins. The trouble in its use results mostly from the fact that it is very soluble and is soon washed down by the rain out of the reach of the roots, which must then draw their nitrogen from the atmosphere by means of the microbic organisms. (Agr. Sci., Vol. IV, p. 264.)

Pagnoul has measured the loss and gain of nitrogen by the soil as the result of the cultivation of special crops. He sowed grass and clover in four pots, but left two others without any crop. The gain of nitrogen permanently fixed in the soil in one year—March, 1888, to March, 1889—was as follows: With no crop the soil gained at the rate of 29 kilograms per hectare per year, with the grass crop 394 kilograms, and with the clover crop 904 kilograms. On the other hand, the total proportion of nitrogen removed from the soil by the drainage water was in each case as follows: No crop, 85; grass, 5; clover, 18. (Agr. Sci., Vol. IV, p. 325.)

## Chapter IX.

### RELATIONS OF CROPS TO MANURES, FERTILIZERS, AND ROTATION.

The preceding section having shown how easily all the valuable nitrates are dissolved and washed away by rain and how completely the permanent fertility of a field depends upon microbic action within the soil, and especially when attached to leguminous plants, we shall therefore not be surprised to learn that expensive and artificial chemical fertilizers and guanos are often less important than the enrichment that comes more naturally by the rotation of crops.

#### ARTIFICIAL FERTILIZERS AND MANURES.

As the result of twelve years' experience, J. W. Sanborn, of Missouri, states that although both science and practice assert the efficacy of artificial fertilizers, yet their *profitable use* is a matter of grave concern both in the granite soil of New England and in the richer soil of the Mississippi Valley. His general conclusions are that we do not need to use as much nitrogen in this climate as in Europe, especially as in England, nor as much as has generally been considered necessary; that enriching by rotation of crops is the preferable method; that nitrogen (*viz*, fertilizers) may be profitably bought only for a few winter or early and narrow-leaved plants, but, as a general truth, broad-leaved plants and those maturing in late summer and in the fall do not require addition of nitrogen to the soil. (Agr. Sci., Vol. I. p. 227.)

From the extensive experiments with fertilizers made at the Ohio Agricultural Experiment Station the following results have been secured, based on both station work and that done by cooperating farmers throughout the State:

*Maize*.—On soils capable of producing 50 bushels of shelled corn to the acre *no* artificial fertilizer is likely to produce an increase of crop sufficient to pay the cost. On soils deficient in fertility, phosphoric acid may be used with profit.

*Wheat*.—As a rule no more wheat has been harvested from plats treated with commercial fertilizers than from those receiving no fertilizers, whereas farm manures produced a marked increase. At the present prices of grain and fertilizers the increase of crops will not cover the cost of the fertilizer.

*Oats*.—Plats receiving nitrates showed a marked superiority in the growing season, but lodged badly before harvest. Muriate of potash gave an insignificant increase. (Agr. Sci., Vol. IV, p. 237.)

E. F. Ladd, of the Agriculture Experiment Station at Geneva, N. Y., urges the necessity of a more thorough and systematic study of climate and soil (Agr. Sci., Vol. IV., p. 36) in order that we may better understand the great diversity and contradictions in the experimental field work, so called. Thus one year's experiments at the same station and with all possible care will show that the "Welcome" oats are vastly more productive than the "White Russian," and the very next year reverses this decision. In the same year a neighboring experiment station operating on the same varieties arrives at opposite conclusions. In 1887 the observations showed that fertilizers did not affect the chemical composition of the grasses, but in 1888 the influence was very marked. Ladd finds that the contradictions in the reports of oat crops for 1885 and 1886 at the Ohio and New York stations are apparently due to considering only such factors as monthly rainfall and temperatures. He urges that the soil temperatures, sunshine, wind, the humidity in the soil, and the aeration of the soil are equally important factors. Any season will give some sort of a crop; but the maximum crop must depend upon the fertilizer and the relation of the fertilizer to the season. Thus Warington has shown that a dry and warm season is most favorable for the action of nitrate of soda, while a moderately wet season is most favorable for the action of sulphate of ammonia. The reason of this appears to be that plants are unable to appropriate to their use the sulphate of ammonia until the salt has become nitrified, and this phenomenon of nitrification does not take place except under the influence of a certain amount of moisture in the soil. A soil that conserves its moisture for a considerable time and is properly cultivated to permit the free permeation of the air gives the best results with sulphate of ammonia, but does not necessarily give the best results with the nitrate of soda, since this is so soluble as to be soon drained away out of reach of the plants. Thus in different seasons, with different fertilizers, we have the crops of wheat shown in the following table:

	Hecto- liters per hectare.
Nitrate of soda and a wet season (1882).....	23.45
Nitrate of soda and a dry warm season (1887).....	31.57
Sulphate of ammonia, wet season (1882).....	28.86
Sulphate of ammonia, warm dry season (1887).....	23.56

Again, crops, like animals, have a certain limit to their capabilities; if the maximum yield is 50 bushels per acre, then it is a waste to put on more fertilizer than needed to attain this limit. Evidently, therefore, we have to study the relation of the climate to the fertilizers and the soil in order to ascertain a very important item in the relation between climates and crops.

Many specific results as to the relation between climates and crops on a large scale are entirely altered from season to season by the chemical influence of the climate on the fertilizer and the soil in general. We have here, therefore, a source of discrepancy that has contributed appreciably to obscure the influence of the climate on the plant.

#### PRIZE CROPS.

Evidently crops of seed or grain depend, primarily, on the amount of nitrogen in the sap, and, secondarily, on the elaboration of those precious nitrates into albuminoids. Hence the recognized need of manures, fertilizers, and leguminous crops. But the study of the remarkable crops of corn raised as so-called prize crops in 1889 demonstrates that excellent results may be obtained on some soils without manures, and is otherwise very instructive, since the heavy manuring in many cases must have been largely counteracted by the waste caused by rain. I condense the following from the monthly reports of the department of agriculture of South Carolina for March, 1890, pp. 233-243:

In 1889 the American Agriculturist offered a prize of \$500 for the largest crop of corn that should be grown on 1 measured acre of ground during the year 1889. Forty-five leading competitors appeared, of whom 10 were from South Carolina. The average of these 10 prize crops from that State gave 105 bushels per acre, whereas the average of the 25 crops from other States was 103.5 bushels per acre. The accompanying table gives most of the more appropriate statistics for the 7 best results in this list of 45:

*Data relative to the best 7 of the 45 competing crops.*

Serial No.	Locality.	Soil.	Quantity of fertilizer.
1	Z. J. Drake, Marlboro County, S. C.	Poor sandy soil..	(a)
2	Alfred Rose, Yates County, N. Y.	Sandy loam.....	800 pounds Mapes corn manure.
3	George Gartner, Pawnee County, Nebr.	Rich black loam.	90 loads barnyard manure.
4	J. Snelling, Barnwell County, S. C.	Sandy loam.....	300 bushels stable manure; 300 bushels cotton seed.
5	L. Peck, Rockdale County, Ga.	.....do.....	4 loads stable manure; 30 bushels heated cotton seed; 1,000 pounds Packard standard fertilizer; 500 pounds cotton-seed meal.
6	B. Gedney, Westchester County, N. Y.	Clay loam .....	800 pounds Mapes corn manure.
7	E. P. Kellenberger, Madison County, Ill.	Sandy loam.....	No fertilizer at all.

*\*Prize crop No. 1.*—The sandy soil had been fertilized in 1887 by Mr. Drake and had yielded in 1888 the great crop of 917 pounds to the acre of lint cotton, and was therefore already profiting by the heavy enrichment that it had received that year. In February, 1889, in preparation for the present contest, Mr. Drake began a new course of manuring, and from that date until June 11 the following material was added to the soil: One thousand bushels stable manure; 867 pounds of German kainit; 867 pounds of cotton-seed meal; 200 pounds of acid phosphate; 1,066 pounds of manipulated guano; 200 pounds of animal bone; 400 pounds nitrate of soda; 600 bushels of whole cotton seed. The total cost of this manure was \$220 and the work in applying it, together with the frequent culture that was given, made the whole expense of the crop \$264. The value of the corn that was raised was \$206, and the value of the manure left in the soil for the next year's crop was at least \$150.



Data relative to the best 7 of the 45 competing crops—Continued.

Serial No.	Variety of seed.	Average distance of hill.	Statistics of harvested crops.							
			Green weight.		Dry weight.		Bushels of kernels.			Water
			Cobs.	Kernels.	Cobs.	Kernels.	Green.	Crib-cured.	Chemically dry.	
		Ft. In.								P. ct.
1	Gourd variety of southern white Dent improved by 20 years of careful selection on his plantation.	4.0×6.0	3,183	14,273	2,726	12,132	255	239	217	14
2	Early Mastodon.....	8.0×12.0	4,134	11,764	2,954	9,764	213	191	174	20
3	do .....	8.0×36.0	1,821	9,559	1,174	7,647	171	151	137	22
4	White Gourd .....	4.0×12.0	1,393	7,316	1,212	6,218	131	122	111	15
5	Large White .....	5.5×48.0	1,826	7,805	1,867	6,196	130	121	110	18
6	King Philip .....	3.5×3.0	1,776	6,683	1,154	5,717	119	112	102	19
7	Eclipse variety early yellow Dent.	6.0×30.0	1,497	7,311	617	5,349	130	105	95	31

With regard to the weather and other items during this season of 1889 at these seven stations I have found only the following notes referring to the prize crop No. 1:

*Cultivation.*—The seed was planted March 2, 5 or 6 kernels to each foot of a row; the plants began to sprout on the 16th; there was a good stand the 25th, and the stalks were thinned out to 1 every 5 or 6 inches on April 8; no hilling was done, but the whole acre was kept perfectly level. The crop was harvested November 25.

*Weather.*—In March the weather was warm and land moist. Good rains on March 3, 10, and 15; rain on 24th; 1 inch of rain on May 26; 6 inches of rain May 30; rain on June 4 and 5; rain on June 9. The season in general was rainy and wet as compared with other years; rains following frequently, and no irrigation was necessary.

The record of largest corn crop up to this date had been that of Doctor Parker, Columbia, S. C., in 1857, who raised 200 bushels to the acre.

The exact measures of all these 45 competing crops have been made the basis of a comparison showing that on the average of the 17 eastern crops the percentage of nitrogenous matter was 10.78, but for 14 southern crops it was 10.33, and for 14 western crops 10.26, showing an imperceptible difference slightly in favor of the eastern climate and soil and seeds.

In respect to the general advantage of fertilizers, and notwithstanding the apparent advantages gained by some of the heavy manuring in these competing crops, attention is called to the fact that competitor No. 7 raised a very fine crop of 130 bushels green or 95 dry bushels to the acre without any fertilizer whatever, and that the crops reported by Nos. 4, 5, and 6 were even less than his in their



green weight, although larger in their dry weight, after what would ordinarily be called very heavy manuring. These facts are quite in accord with the general results of work at experimental farms, which, according to the South Carolina department of agriculture, have shown that increasing the amounts of the fertilizers beyond a certain point gives no corresponding increase in the amount of grain, and but few of the applications pay for their cost. There is abundant experimental proof that for any given soil there is a limit to the amount of profitable manuring. The process of improving the soil, like the process of fattening cattle, is comparatively gradual and requires time. The margin of profit in the application of manures is narrower than is generally supposed. It is equally important to attend to the selection of the seed, the thorough cultivation, and the natural fertilization that results from the cultivation of the Leguminosæ and the rotation of crops.

## PART II.—EXPERIENCE IN OPEN AIR OR NATURAL CLIMATE.

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### Chapter X.

#### STUDIES IN PHENOLOGY.

Under the general heading we shall consider, first, the wild plants and their natural habits; second, the plants cultivated at experiment stations under instructive experimental conditions, and, third, the statistics of each and the experience of farmers in general from a practical point of view. The study of the forest or natural habits of plants leads us into the phenology of plant life.

Phenology is a term first applied by Ch. Morren to that branch of science which studies the periodic phenomena in the vegetable and animal world in so far as they depend upon the climate of any locality. Among the prominent students of this subject, one of the most minute observers was Karl Fritsch, of Austria, who in his *Instructions* (1859) gives some account of the literature of similar works up to that date. He distinguishes the following epochs in the lives of plants, and especially recommends the observation of perennial or forest trees that have remained undisturbed for at least several years. His epochs are:

(1) The first flower.

(2) The first ripe fruit.

The next important are, for the annuals:

(3) The date of sowing.

(4) The date of first visible sprouting.

In order to assure greater precision he adds:

(5) The first formation of spikes or ears.

As Fritsch considers that the development of the plant so far as its vegetative process is concerned depends principally upon temperature and moisture, but that its reproductive process depends principally upon the influence of direct sunlight, therefore he adds a sixth epoch for trees and shrubs—viz:

(6) The first unfolding of the leaf or the leaf bud or frondescence.

This is the epoch when by the swelling of the buds a bright zone is recognized which opens out and the green leaf issues forth. Cor-

responding with the formation of the leaf is its ripening and fall from the tree, which Fritsch adds to his list of epochs, viz:

(7) The fall of the leaf or the time when the tree has shed fully one-half of its leaves; as the wind and heavy rains accelerate this process the date is liable to considerable uncertainty independent of the vitality of the plant. Therefore, in this, as in all other epochs, Fritsch, in endeavoring to lay the foundations of the study, rejected those cases in which any unusual phenomenon, such as wind or drought or insects, had a decided influence on the observed dates.

Many plants blossom a second time in the autumn, although they may not ripen their fruits; therefore in special cases Fritsch adds an eighth epoch, viz:

(8) The second date of flowering. Of course it is understood that if the second flowering is brought about artificially, as by irrigation, pruning, or mowing, that fact must be mentioned.

When the flowers blossom in clusters, such that the individuals are lost sight of in the general effect, then, in addition to the first flower, we note the following item:

(9) The general flowering or the time when the flowers are most uniformly distributed over the plant.

For 118 varieties Fritsch gives in detail the phenomena that characterize the date of the ripening of the fruit. He also gives an equally elaborate system of observations on birds, mammals, fishes, reptiles, and insects, and especially the mollusks or garden snails and slugs.

#### **THE RELATION OF TEMPERATURE AND SUNSHINE TO THE DEVELOPMENT OF PLANTS—THERMOMETRIC AND ACTINOMETRIC CONSTANTS.**

Reaumur was the first to make an exact comparison of the different quantities of heat required to bring a plant up to the given stage of maturity, and since then many authors have written on this subject.

I will here give a brief summary of views that have been held by prominent authorities as to the proper method of ascertaining and stating the relation between temperature and the development of plants.

Reaumur (1735) adopted simply the sum of the mean daily temperatures of the air as recorded by a thermometer in the shade and counting from any given phenological epoch to any other epoch. He employed the average of the daily maximum and minimum as a sufficiently close approximation to the average daily temperatures, and evidently in the absence of hourly observations any of the recognized combinations of observations may be used for this purpose. Reaumur found from his observations that the sum of these daily temperatures was approximately constant for the period of development of any plant from year to year; hence this constant sum is called a thermal constant in phenology. For the three growing

months—April, May, and June, 1734—the sum of the daily temperatures for ninety-one days was equivalent to  $1,160^{\circ}$  C., but for 1735 it was  $1,015^{\circ}$  C., whence he concluded that the ripening of the vegetation would be retarded in 1735 as compared with the preceding year.

This idea had been familiar to Reaumur for some time previously, and in 1735, as cited by Gasparin, *Met. Agric.*, Vol. II, 1st ed., Paris, 1844, he says:

It would be interesting to continue such comparisons between the temperature and the epoch of ripening and to push the study even further, comparing the sum of the degrees of heat for one year with the similar sums of temperatures for many other years; it would be interesting to make comparisons of the sums that are effective during any given year in warm countries with the effective sums in cold and temperate climates, or to compare among themselves the sums for the same months in different countries.

Again, Reaumur says:

The same grain is harvested in very different climates. It would be interesting to make a comparison of the sum of the temperatures for the months during which the cereals accomplish the greater part of their growth and arrive at a perfect maturity both in warm countries like Spain and Africa, in temperate countries like France, and in cold countries like those of the extreme north.

This passage, says Gasparin, is the germ of all the works which have been executed since that time in order to determine the total quantity of heat necessary to the ripening of the different plants that have been cultivated by man.

Adanson (1750) disregarded all temperatures below  $0^{\circ}$  C., and took only the sums of the positive temperatures. He expressed the law as follows: The development of the bud is determined by the sum of the daily mean temperatures since the beginning of the year.

Humboldt early insisted upon the necessity of taking the sunlight itself as such into consideration in studying the laws of plant life.

Boussingault (1837), in his *Rural Economy*, introduces the idea of time by adopting the principle that the duration of any vegetating period multiplied by the mean temperature of the air during that period gives a constant product. He takes the sum of the temperatures from the time when vegetation begins and finds the length of the period of vegetation from germination up to any phase, to vary from year to year, inversely as the total sums of the daily temperatures.

Thus, for winter wheat to ripen, he found that there was necessary a sum total of from  $1,900^{\circ}$  to  $2,000^{\circ}$  C. of mean daily air temperatures in the shade, which constant sum is equivalent to saying that the average temperature of the growing period is found by dividing this number by the number of days. This method of computation takes

no account of any temperature at which the growth of wheat ceases. A lower limit for such temperature has been adopted by several investigators, such as the  $0^{\circ}$  C., already mentioned as adopted by Adanson. An upper limit has not yet been ascertained. Edwards and Colin put it at  $22^{\circ}$  C.; but in Venezuela Codazzi found wheat to mature under a constant temperature of  $23^{\circ}$  or  $24^{\circ}$  C. throughout the whole period of vegetation, and, as we shall see hereafter, the upper limit undoubtedly depends upon the humidity of the air, the moisture of the soil, and the total radiation from the sun quite as much as upon temperature. Similarly Marié-Davy calls attention to the fact that maize grows poorly at Paris, where it is cloudy and warm, but well in Alsace, where it is dry and clear, the temperature of the air averaging about the same in both, the difference being in the quantity of sunshine and rain.

Gasparin (1844) adopted the mean temperature of the day as derived from observations made at any convenient hours and took the sum of such temperatures from and after the date at which the plants, especially the cereals, begin to actively develop, or to vegetate, or when the sap flows readily throughout the day. For this "effective temperature" he adopts  $5^{\circ}$  C.

Subsequently Gasparin adopted a thermometer placed in full sunshine on the sod as giving a temperature more appropriate to plant studies, but still retaining the lower limit of  $5^{\circ}$  C. for the mean daily temperature of the initial date. Thus he obtained for wheat a sum total of  $2,450^{\circ}$  C. as the sum of the effective daily temperatures from sowing to maturity.

Gasparin also observed the temperature of a blackened metallic disk in the sunshine and the temperature of the sunny side of a vertical wall, and again the temperature of a thermometer at the surface of a sandy, horizontal soil, all in full sunshine. He recognized that the loss of heat by evaporation must keep the temperature of the soil slightly lower than that of the surface of the wall; but, in default of better methods, he kept a record of the temperature of the wall for many years. From his average results I give the following abstract:

*Observations by Gasparin at 2 p. m. daily.*

Locality.	Year.	January.		August.	
		Air.	Wall.	Air.	Wall.
Orange.....	1836-1850	6.7	15.4	30.2	44.1
Paris.....	1838-1850	4.0	6.8	23.6	30.2
Peissenberg (Munich).....	1786	-1.8	11.0	14.6	22.0

The warmth in the sunshine is to the warmth of the air in the shade as though one had been transported in latitude from 3 to 6 degrees farther south.

Another study into the total radiation received by the plants in sunshine was made by Gasparin by placing a thermometer in the center of a globe 1 decimeter in diameter, made of thin copper and covered with a layer of lampblack. Having found by comparison that bulbs of different sizes gave different temperatures, he recommends this size to all meteorologists; but I do not know of observations made by others until Violle (1879) urged the same construction and size for his conjugate bulbs. This bulb in the full sunshine and at a standard distance above the ground seemed, to Gasparin, to give what he calls the temperature of a dry opaque body. The difference between this and the temperature of the air gave a surplus showing the effect of solar radiation on the leaves; again, the difference between this dry, black bulb and the temperature of the surface of the moist earth gave him some idea of the nature and amount of the influence of the sunshine on the surface of the soil, which he illustrates by the following table, derived from seventeen years of observations:

*Temperature at 2 p. m.*

Month.	Soil.	Black bulb in the air.	Month.	Soil.	Black bulb in the air.
January .....	6.7	15.4	August .....	43.1	44.1
February .....	12.7	22.0	September .....	31.4	38.9
March .....	19.1	28.5	October .....	20.2	28.7
April .....	25.5	29.4	November .....	12.1	19.4
May .....	27.6	34.4	December .....	5.9	15.4
June .....	40.9	39.4	Average .....	24.4	29.6
July .....	45.3	43.4			

On this table Gasparin remarks:

We see how much the difference of temperatures of the stems and the roots ought to modify the flow of the sap, and there is here an interesting subject for physiological study which should redound to the profit of agriculture. The solar heat contributes also in a remarkable manner to cause the differences in the vegetation of the mountains and the plains. On mountain tops it is the heat of the surface soil and the roots in the sunshine and the effect of sunshine on the leaves that makes possible the existence of a great variety of phænogams. The direct action of the solar heat is the explanation of the possibility of raising cereals and other southern crops in high northern latitudes.

Gasparin (1852, p. 100) gave the following table, compiled for western Europe, showing the mean temperatures of the day during which the respective plants leaf out, flower, or ripen. This early effort to apply meteorological data to the study of plants takes no account, as the author himself says, of other meteorological conditions than temperature such as introduce considerable variations into the phænological phenomena, but he gives it in hopes of helping thus to fix the rela-

tions of natural vegetation to cultivated plants. If in addition to recording temperature, rainfall, sunshine, and other meteorological elements, we could keep a parallel record of the stages of development of cultivated and uncultivated plants we could use the latter as an index to the effect of the weather during any season and predict from that the behavior of the cultivated plants.

*Temperatures at the respective phenological epochs for plants in European climates (by Gasparin).*

(1) LEAFING.

	° C.
Wild honeysuckle ( <i>Lonicera peryclimenum</i> )	2.0
Thorny gooseberry ( <i>Ribes uva crispa</i> )	5.0
Lilac	5.0
Ordinary currant ( <i>Ribes rubra</i> )	6.0
Broad-leaved willow ( <i>Salix caprea</i> )	6.0
Horse-chestnut ( <i>Æsculus hippocastanum</i> )	7.5
Apple tree ( <i>Malus communis</i> ); cherry tree ( <i>Cerasus communis</i> )	8.0
Fig tree ( <i>Ficus carica</i> )	8.0
Grapevine shoots	9.5
Mulberry tree covered with leaf-buds; walnut tree	9.8
Sprouting of lucerne grass	10.0
Alder tree	12.0
Oak; mulberry tree developing leaves	12.7
Acacia ( <i>Robinia pseudoacacia</i> )	13.5

(2) FLOWERING.

Hazelnut tree ( <i>Corylus avellana</i> ); cypress	3.0
Furze or gorse ( <i>Ulex europæus</i> ); box ( <i>Buxus sempervirens</i> ); white poplar ( <i>Populus alba</i> )	4.0
Broad-leaved willow; honeysuckle	5.0
Peach tree	5.4
Almond tree; apricot tree	6.0
Pear tree	7.0
Elm; apple tree	7.5
Cherry tree; colza	8.0
Lilac; strawberry plant	9.5
Broom ( <i>Genista scoparia</i> )	10.0
Beans	11.5
Horse-chestnut	12.0
Hawthorn or may ( <i>Mespilus oxycantha</i> )	12.5
Sainfoin or French grass ( <i>Hedysarum onobrychis</i> , Leguminosæ)	12.7
Acacia ( <i>Robinia</i> )	14.0
Rye	14.2
Buckthorn ( <i>Rhamnus paliurus</i> )	15.0
Oats	16.0
Wheat; barley	16.3
Chestnut tree:	
First flower	16.6
Full flower	17.5
Grapevine:	
Full flower	18.2
Flower passed	19.0
Indian corn; hemp; olive tree	19.0



## (3) RIPENING.

During increasing heat:	° C.
Fruit of the elm <sup>o</sup> tree .....	12.0
Green peas .....	14.2
First cherries; broad beans .....	16.0
First mowing of sainfoin .....	17.0
Currants; raspberries; strawberries; cherries .....	17.8
Morella cherry tree; apricot; plum tree; barley; oats .....	18.0
Rye .....	19.0
Peach tree; harvest of corn .....	20.0
First figs; green gage plums .....	21.0
First grapes, called madeleine; melons in free earth .....	22.5
Hemp .....	22.6
During decreasing heat (for fruits which have received a sufficient quantity of increasing heat):	
Horse-chestnut .....	18.2
Indian corn; potatoes .....	17.0
Walnuts and chestnuts .....	16.2
Pomegranates .....	15.0
Saffron .....	13.0
Olives .....	10.0

NOTE.—It can be easily understood that the fruits which require the greatest prolongation of heat ripen last and are gathered at periods of the lowest temperatures.

Lachmann, in his *Entwicklung der Vegetation*, counts the sum total of all the temperatures at his station (Braunschweig, Germany) from February 21 onward.

Linsser, for north temperate countries, counts from the date when the temperature 0° C. is attained, but for warmer countries he counts from the date when the lowest temperature of the year is attained; which date would, according to his calculations, be the 8th of February at Braunschweig instead of the 21st of February; but, according to the normal values resulting from the thirty years of observation by Lachmann, this change would only make his sum totals about 10° C. larger.

Tomaschek, as quoted by Fritsch (1866, LXIII, p. 297), takes the mean of all positive temperatures as observed at 6 a. m., 2 p. m., and 10 p. m., omitting the individual negative observations instead of the negative daily averages. He counts the sums from January 1; this method gives figures that agree very closely, at least in Europe, with those given by Fritsch's method.

Kabsch, as quoted by Fritsch, attempted an improvement on the method of Boussingault. His formula is especially appropriate to the annuals, but not to the perennial plants. His method of computing the thermal constant is expressed by Fritsch in the following formula:

$$x = t \pm \left( \frac{h}{12} t \right) c - C$$

where the notation is as follows:  $C$  is the total heat from the date of sowing up to the date of sprouting;  $x$  is the thermal constant from one phase to the next, such as from sprouting to flowering;  $t$  is the number of days from sprouting to flowering;  $c$  is the mean daily temperature from sprouting to flowering;  $t c$  is the total sum of mean daily temperatures from sprouting to flowering; as this temperature is principally active during the daytime, therefore one-twelfth of  $t c$  represents the efficient heat during an hour;  $h$  is the duration in hours of an average growing day, viz, from sunrise to sunset; therefore one-twelfth of the product  $c h t$  represents the total heat that has been utilized by the plant.

The method of reasoning by which Kabsch arrives at the above formula, which I have quoted from Fritsch, is not known to me.

Sachs, by direct experiment, finds that for each plant there is a temperature most favorable to its growth and two other limits, minimum and maximum, beyond which it will not grow.

Deblanchis finds that the temperature on which vegetation depends is not the ordinary temperature of the air as given by a sheltered thermometer; he prefers to approximate to the temperature of the leaf of the plant by the use of his "vegetation-thermoscope," which is an ordinary minimum thermometer covered with green muslin and kept moist, as in the ordinary wet-bulb thermometer. He places his thermometer at one and a half meters above the soil and in full exposure to sun and sky. Evidently the sum total of his temperatures will be between the sums of the ordinary wet-bulb and the ordinary dry-bulb thermometers, but must differ greatly from the temperature of the roots on which the growth of the plant primarily depends.

Hoffmann prefers to take for the daily temperature the excess above freezing of the maximum thermometer exposed to full sunshine and free air. Hoffmann's temperatures approach more nearly the temperature of the roots within a few inches of the surface of the ground. Besides taking the sums of the average daily temperatures of the shaded air thermometer, omitting all negative values or all those below freezing point, Hoffmann also took the sum of the bright bulb in vacuo and of the black bulb in vacuo, both in full sunshine; these latter temperatures are generally higher than those of the roots and much higher than those of the leaves. Hoffmann prefers to use the readings of the bright bulb in vacuo.

Hervé Mangon (1879) modifies Gasparin's method slightly in that he takes account of the shade temperatures of the air from the date of sowing up to the date of harvest, rejecting all cases where the mean daily temperature in the shade is less than  $6^{\circ}$  C.; he had been led to think that the vegetation of cereals and other important crops ceases below this temperature. Thus he determines the sum total

needed for ripening the crops of the varieties of wheat ordinarily cultivated in Normandy, as shown in the following table:

Date of sowing.	Date of harvesting.	Sums of daily temperatures.		
		From sowing to Feb. 29.	From Mar. 1 to harvest.	Total.
		° C.	° C.	° C.
Nov. 17, 1869	Aug. 12, 1870	856	2,000	2,856
Nov. 5, 1870	Aug. 20, 1871	359	2,158	2,517
Nov. 27, 1871	Aug. 4, 1872	305	1,914	2,309
Nov. 5, 1872	Aug. 8, 1873	632	1,806	2,438
Nov. 27, 1874	Aug. 10, 1875	339	1,880	2,219
Nov. 4, 1875	Aug. 3, 1876	490	1,828	2,318
Nov. 18, 1876	Aug. 2, 1877	701	1,769	2,470
Dec. 6, 1877	Aug. 7, 1878	367	2,035	2,402
Dec. 21, 1878	Sept. 1, 1879	171	2,065	2,256
Average, Nov. 17.....	Aug. 8.....	455	1,824	2,379

By similar calculations Hervé Mangon obtains for other crops as cultivated in Normandy the following results:

	Mean date.		Sums of daily temperatures from sowing to harvest.
	Sowing.	Harvesting.	
			° C.
Oats.....	Mar. 7	Aug. 5	1,826
Do.....	Nov. 8	Aug. 20	2,197
Barley.....	Apr. 13	Aug. 18	1,810
Beans.....	Mar. 3	Aug. 25	2,210
Buckwheat.....	June 10	Sept. 10	1,525

Hervé Mangon concludes his essay with two important practical rules, deduced from his data relative to the climate and crops of the department of La Manche: (1) In a mild and uniform climate, like that of the northwest of France, there is always an advantage in sowing the seed early in the autumn; (2) by computing annually the sums of the degrees of temperature observed since the date of sowing and by consulting the numerical tables given in this memoir one can, with great accuracy, calculate four or six weeks in advance the date of the approaching harvests of the respective plants.

The tables given by Mangon for his locality can be reproduced for American stations wherever the meteorological observations and the dates of planting and harvesting are recorded; although it may be possible to consider more minute details of climate and soil than he has done, yet the success attained by him in his elementary collation of fundamental data must stimulate to similar work in this country.

From the data given by Mangon, Marié-Davy deduces some further phenological constants which will be useful, viz, for winter wheat in Normandy, the sum of the daily temperatures in the shade, rejecting all below 6° C., from sowing to germination is 85° C.; from germination to heading, 555° C.; from heading to maturity, 1,810° C. This gives from sowing to heading 640° C., whereas Gasparin, following his own rule, which takes the sum of all temperatures after the date at which the temperature of 5° C. is attained, finds 430° for this constant.

Wheat begins to grow visibly when the mean daily temperature is about 6° C. This mean daily temperature is attained on the average of many years on the dates given in the second column of the following table. (See Marié-Davy, 1881 and 1882, p. 184.) The average dates of harvest are given in the third column; the interval or growing period in the fourth column; the fifth column contains the sums of the mean daily temperatures of the air in the shade (after the date on which a mean temperature of 6° was attained), the sixth column gives the sums of the mean daily temperatures of the thermometer in the full sunshine, as determined by Gasparin. The close agreement of the two latter numbers is considered by Marié-Davy an argument in favor of the idea that temperatures in the sunshine are better than those in the shade as a measure of the influence of heat and light on the growth of plants.

Place.	Date of 6° C.	Wheat harvest.	Grow- ing pe- riod.	Sum of shade temper- atures.	Sum of sunshine temper- atures.
			<i>Days.</i>	<i>° C.</i>	
Orange.....	Mar. 1	June 25	117	1,601	2,468
Paris.....	Mar. 15	Aug. 1	138	1,970	2,433
Upsala.....	Apr. 20	Aug. 20	122	1,545	.....
Lyndon.....	June 15	Aug. 27	72	675	.....

Balland (see Marié-Davy, 1881, p. 186) has made a perfectly similar computation with reference to the ripening of wheat cultivated on a large scale at Orleansville, in Algeria, with the following results:

1878 .....	2,498
1879 .....	2,433
Average .....	2,462

The results of Mangon, Balland, and Gasparin agree so closely that a strong argument seems to be afforded in favor of using the thermometer exposed to the full sunshine. The differences in their results are quite comparable to the differences found by Vilmorin to exist between different varieties of the same seed.

The values of the thermometric constants, as computed by Herve Mangon's method, for other grains cultivated in Normandy are given

in the following table, where the figures represent the sums of sunshine temperatures necessary to complete the growth from germination to harvest.

Plant.	Sunshine temperature.	Plant.	Sunshine temperature.
	° C.		° C.
Algerian wheat .....	2,462	Normandy barley .....	1,810
Normandy wheat .....	2,865	Normandy beans .....	2,210
Normandy oats .....	2,197	Normandy buckwheat .....	1,579

Marié-Davy (1881), in his chapter on the influence of heat on the time required for vegetation, adopts the principle enunciated by Boussingault, of the equality of the sum total of the temperatures, but thinks that the temperature required to bring a plant to the flowering stage is the sum of the mean daily temperatures in the full sunshine, and not the temperature of the air in the shade. According to his view, the heat is needed in the soil in the early part of the growth of the plant; but after the flower is formed, or during the process of perfecting the fruit, sunlight is needed, and during this stage he uses the actinometric degrees of the Arago-Davy actinometer as an index of the progress of the plant. I have, therefore, in the following table collated the figures given by him for wheat. The third column gives the sum total of the mean daily shade temperatures, counted from February 1 of each year up to the date at which the total amounts to 1,264° C., or within half a day thereof, that being the adopted shade constant for the flowering of wheat that was sown on or about the 21st of March. The fourth and fifth columns give the dates and sum totals of temperatures observed with a naked-bulb thermometer on the grass in the full sunshine, assuming 1,569° C. as the thermal constant for this thermometer. The sixth column gives the observed dates of flowering. As these dates agree with those in the fourth column better than with those in the second column, Marié-Davy considers them as confirming him in the use of the unprotected solar thermometer. In order to bring out the total effect of sunlight and sun heat Marié-Davy has computed the sum total of actinometric degrees from February 1 up to the dates given in column 2 and in column 4, respectively. These results are given in columns 7 and 8, which show that 1878 was a very precocious year, as compared with the others, in that the date of flowering was very early, but the sum total of its actinometric degrees was very small and its crops were very poor. 1879 and 1877 show larger actinometric sums, but the largest sums are given by the years 1873, 1874, 1875, and 1876, which were also very excellent crop years.

*Date of flowering of wheat at Montrouge, France.*

[See Marié-Davy, 1880, pp. 181-215.]

Year.	Shade temperatures.		Sun thermometer.		Observed date of flowering.	Actinometric percentages.	
	Date.	Sum total.	Date.	Sum total.		Shade dates.	Sun dates.
		°C.		°C.			
1879.....	June 21	1264	June 21	1569	June 21	4063	4063
1878.....	June 6	1268	June 10	1566	.....	3467	3666
1877.....	June 12	1274	June 15	1578	June 15	3976	4073
1876.....	June 15	1269	June 19	1567	June 19	4376	4588
1875.....	June 7	1264	June 13	1574	.....	4298	4603
1874.....	June 10	1277	.....	.....	June 9	4506	.....
1873.....	June 19	1256	.....	.....	.....	4296	.....

Marié-Davy concludes that by keeping a daily summation of actinometric degrees it becomes possible, even at the epoch of flowering of wheat, to estimate in a very approximate manner what will be the final value of the resulting harvest. At this moment, even if we have already measured the sum of the products which should be applicable to the formation of grain, we can not be absolutely cert in that the harvest will correspond to our expectations. A certain time is necessary for the nutrient particles to traverse the various parts of the stem up to the seed, and a certain quantity of water is necessary for this transportation. An excessive dryness or heat will interfere with this movement and will give a poorly developed grain, notwithstanding the abundance of nutrition reserved for it within the plant. But although water and nutrition are as important as heat and light, still we find that predictions based on actinometric degrees alone are very reliable.

According to Georges Coutagne, the law that connects the rate of development of a plant with its temperature must be such that it has a maximum value for a special temperature and diminishes as we depart from this down to a zero rate at the freezing point and also to zero at some higher temperature at present unknown; all this is on the assumption that the sunlight, moisture, and winds are such as to enable the plant to do its very best at the given temperature. If this law were known we could then determine whether a plant would live and flourish in any given climate.

This law of growth has been expressed by Georges Coutagne, as quoted by Marié-Davy (1883, p. 227), by the following notation and formula. Let—

$v$  be the rate of development of the plant, assuming that other conditions are so adjusted that it attains the maximum growth possible for the given temperature;

$x$  be the temperature of the plant;



$a$  be a coefficient that defines the rate of development so that the reciprocal of  $a$  defines the longevity of the plant;

$n$  be a coefficient that defines the sensitiveness of the plant to temperature, so that as  $n$  increases a given change in  $x$  has a less effect on the rate of growth and therefore the plant can flourish in a wider range of temperature; therefore its geographical distribution may be wider, hence Coutagne calls  $n$  a coefficient of ubiquity;

$c$  be the temperature at which the most rapid development is possible under the most favorable conditions of growth or the temperature optimum; plants with a large value of  $c$  must live nearer the equator than those having small values of  $c$ ; therefore  $c$  is called the index of tropicality.

According to Coutagne these quantities are bound together by the formula:

$$v = a e^{-\left(\frac{x-c}{n}\right)^2}$$

This formula represents the momentary rate of development, so that the total duration of the growth is to be found by integrating this expression, which result is written as follows:

$$L = \int_{x_2}^{x_1} a e^{-\left(\frac{x-c}{n}\right)^2} dx$$

Van Tieghem, like Coutagne and others, finds that for each special phase of vegetation, germination, heading, flowering, or ripening, and for each age of a perennial plant there exists a special relation between the temperature, the light, the moisture, and the chemical composition of the soil and water that is most favorable to growth. We have, therefore, to decide whether the same formula of development can represent the growth in each of these phases as well as throughout the whole career of the plant. As we have before said, the plant can only rearrange the inorganic products that it receives and develop its own structure by utilizing the molecular energy contained in the sunshine or some equivalent light. Its growth does not depend upon any force contained within the plant nor on the temperature, as such, but on the quality of the radiation; therefore any formula that considers temperature only must be a very imperfect presentation of the growth, especially in those stages subsequent to the full development of the leaf and flower.

Lippincott (1863, p. 506) gives a few items relative to the phenology of wheat in America and the origin of the varieties known as Lambert's Mediterranean China (or Black Tea), Hunter's, Fenton, Piper's, which were all due to judicious selection and careful culture.

The average wheat crop of England is stated to be 36 bushels per acre and that of the United States 15 or less, which large difference is, he thinks, the result of judicious cultivation and care in the choice



of seed rather than the influence of climate, since large crops have been and can be raised in this country.

The injurious influence of hot, moist, and rainy weather has, he thinks, a general tendency to deteriorate the quality of American wheat, as the plant needs a hot and dry climate. Moisture defines the southern limit of wheat cultivation while the northern limit has not yet been found. In 1853 the growing season in England was too cold to ripen, the average being  $57^{\circ}$  F. for July and  $59^{\circ}$  F. for August, so that only one-half or one-third of the usual crop of wheat was harvested.

In Bogota, Colombia, where the temperature of the high plains is quite low, wheat that is sown in February is harvested in the last week of July, or in 147 days, at a mean temperature of  $58^{\circ}$  or  $59^{\circ}$  F. At Quinchuqui wheat is sown in February and reaped in July at a mean temperature of  $57^{\circ}$  or  $58^{\circ}$  F. Hence Lippincott concludes that in general wheat requires a mean temperature of  $60^{\circ}$  during the last month of its maturity, or a mean temperature of  $56^{\circ}$  during the whole period of growth.

In England in 1860 wheat sown March 28 ripened August 20. Of these 145 days there were 133 that had temperatures above  $42^{\circ}$  F. In 1861 130 days were required of temperatures above  $42^{\circ}$  F.

When the temperature of the soil during the last phase of growth (viz., from earing to maturity) falls below  $58^{\circ}$  to  $60^{\circ}$  F. no progress is made in the growth, and unless  $60^{\circ}$  is exceeded the crop never fairly ripens. These figures appear to accord closely with the requirements of the wheat plant in the United States, where it is found that those regions having a mean temperature for May between  $58^{\circ}$  and  $60^{\circ}$  F. can not mature the wheat in May, but those having a June temperature above  $61^{\circ}$  can ripen the wheat in that month. Those having a temperature of  $61^{\circ}$  in July can mature spring wheat which is sown the 10th of April or the 10th of May. Those having a mean temperature of  $61^{\circ}$  in May can mature the winter wheat in that month.

Lippincott gives the following items: At Arnstadt, Germany, wheat requires from flowering to maturity 53 days at a mean temperature of  $63^{\circ}$  F., or a total of  $3,339^{\circ}$  F.:

At Richmond, Va., Japan wheat headed April 30, 1860, and was reaped June 14, or 46 days, with a sum total of mean daily temperatures of  $3,086^{\circ}$  F.:

At Haddonfield, N. J., Mediterranean wheat sown early, headed May 18, 1864, and matured June 30, or 44 days, with a sum total of  $3,024^{\circ}$  F. of mean daily shade temperatures:

In Monroe County, N. Y., wheat headed May 10, 1859, and matured July 8, or 56 days, with a sum total of  $3,562^{\circ}$  F.

The preceding meager data are all that Lippincott was able to find

with regard to wheat in America after an extensive research, but within the past few years much more attention has been given to this subject.

The differences between the quantities of heat required in England and America and the differences in the varieties of the wheat were apparent to Lippincott. Thus, he finds that in England the lengths of the periods and the sums of the temperatures were as follows: In 1860 a period of 59 days and a sum of  $3,562^{\circ}$  F.; in 1861 a period of 50 days and a sum of  $3,225^{\circ}$  F.; in 1862 a period of 56 days and a sum of  $3,406^{\circ}$  F. The reduction of the mean temperature during two months of 1853 by merely  $2^{\circ}$  F. cut off one-third of the crop and brought a famine that was already foreseen in July, 1853. On the other hand, it increased the exportation of wheat and flour from the United States from \$14,000,000 in 1852 and \$19,000,000 in 1853 to \$49,000,000 in 1854.

A careful study of the sum totals of rainfall, temperature, and sunshine should enable one, in general, to foresee similar failures and corresponding successes in the crops of any region.

#### QUETELET.

The suggestive, but sketchy, studies of earlier writers on thermal constants were supplemented by more elaborate investigations and calculations of statistics by Quetelet (1849) in his *Climate of Belgium*, from his own summary (p. 62), etc., I take the following notes:

The details hitherto given show sufficiently that the relative conditions of vegetation change at all times of the year in two countries situated at a distance from each other. Acceleration and retardation are quantities essentially variable, and it is erroneous to say that one locality has its budding period ten or twenty days sooner, for example, than another. This difference may be correct for one season of the year and entirely wrong for another; and, moreover, we can only pretend to state a fact which applies to the majority of plants.

Nevertheless the differences in the periods of budding are not so variable but that we can assign to them values very useful to consult in practice. On the other hand, science needs to establish some well-determined facts in order to arrive later at the knowledge of the laws upon which these variations depend. I believe that in the actual state of things I shall be able to settle upon the following epochs, in order not to multiply too much the terms of comparison. Moreover, the numerical tables justify, to a certain extent, the distinctions which I lay down.

Let us first observe that the awakening of the plants is brought about by the cessation of the cold, and it suffices to consult the tables of temperatures for the different countries to determine the average epoch at which many plants will put out their leaves or their flowers. These first indications, which it is well to collect, still do not determine, however, the general movement of vegetation which may

manifest itself more or less slowly. They are given by the budding of the *Galantus nivalis*, of the *Crocus vernus*, by the appearance of the catkins of the *Corylus avellana*, of the leaves of the *Ribes grossularia*, of the *Sambucus nigra*, of the honeysuckle, and of some spireas.

The falling of the leaves is also determined by the temperature, and in our climate generally takes place after the first frosts. This period and that previously mentioned come ordinarily at the two limits of winter, and they separate to make place for the different stages of vegetation in proportion as the cold of winter has a less duration. The winter sleep lasts in our climate from three to four months; in southern countries it is very much shorter. We can even imagine a line on the surface of the globe where it ceases altogether for the generality of plants.<sup>a</sup>

The great movement of vegetation commences in Belgium in the middle of March and terminates at the end of April. I will call this the period of leafing (*feuillaison*), because during this interval the different plants are covered with their verdure and some of them show their first flowers.

The second period is that of flowering (*floraison*), which in our climate would include the months of May and June and the first half of July.

The third period would then come, which is that of ripening (*fructification*).

These three great periods should undoubtedly be in their turn subdivided, but the present state of the observations does not allow of such detail. It is understood, moreover, that the names I have given to them only serve to designate the principal phases of vegetation which take place. Thus, in making the general table [omitted—C. A.] I have classed the different plants according to the following seasons:

*Awakening of the plants.*—This period is determined by the plants comprised in the [omitted] table.

*Leafing.*—This period comprises the plants which, in Brussels, put out their leaves from the 15th of March to the 30th of April, and which bud during the same two months.

*Flowering.*—I have made use of the plants which have flowered or brought forth their fruit from the 1st of May to the 15th of July.

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<sup>a</sup> As I have already observed elsewhere, the awakening is an epoch that is not the same for all plants. I mean to speak here only of the epoch when the sap begins to circulate in the majority of the plants which grow in our climate. "All plants do not begin to vegetate at the same period," says M. Ch. Martins, in the Botanical Expedition along the Northern Coasts of Norway. "Thus in some the sap begins to mount when the thermometer is only a few degrees above zero (centigrade); others need 10 or 12 degrees of heat, while those in warm climates require a temperature of from 15° to 20° C. In a word, every plant has its own thermometric scale, whose zero corresponds with the minimum temperature at which vegetation is possible for it. Consequently, when we wish to determine the sum total of the temperature that has determined the date of flowering (*floraison*) of each of these plants it is logical to only consider for each plant the sum of the degrees of temperature above zero (centigrade), since these temperatures are the only ones that have been efficient in inducing or sustaining their growth." In tropical countries the great fluctuations in the vegetable kingdom are not regulated by the same meteorological elements as are effective with us; there the rainy season produces very nearly the same effects as the cold season does in our climates.

*Ripening.*—This period comprises the stage of vegetation, which, for Brussels, extends from the 15th of July to the falling of the leaves, the last limit of the period with which we are occupied here.

This classification has allowed me to put into [the omitted] table the observations gathered from other sources, as well as from the system of comparative observations which the Royal Academy of Belgium has succeeded in establishing at Brussels.

*The average influence of location on the annual progress of vegetation.*

Locality.	Position.			Acceleration or retardation of phases of vegetation relative to Brussels.				
	Longi- tude from Paris.	Lati- tude north.	Alti- tude.	Awak- ening.	Leaf- ing.	Flow- ering.	Fruit- ing.	Fall of leaf.
	<i>m. s.</i>	<i>° '</i>	<i>Meters.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
Naples.....	47 40 E.	40 52	.....	.....	+88	.....	.....	.....
Alais.....	-6 57 E.	44 7	148	.....	+14	+12	+40	.....
Venice.....	40 4 E.	45 28	11	+20	+4	+18	+30	-19
Parma.....	81 59 E.	44 48	49	+2	+2	+16	+51	-10
Guastalla.....	33 15 E.	44 55	.....	+14	+7	+18	+49	.....
Geneva.....	15 15 E.	46 12	408	.....	-1	-6	+12	.....
Lausanne.....	17 11 E.	46 31	538	.....	-2	+11	.....	.....
Carlsruhe.....	24 17 E.	48 59	380	-11	-3	+15	.....	+11
Dijon.....	10 48 E.	47 19	240	-3	-1	+6	+15	+18
Paris.....	0 0	48 58	87	.....	+6	+5	.....	.....
Montmorency.....	0 30 W.	49 0	140	.....	-5	-12	+14	.....
Valognes.....	15 14 W.	49 31	.....	+27	0	-1	+19	.....
Polperro, England.....	.....	50 15	.....	+41	+10	-2	.....	.....
Swaffham, England.....	.....	.....	.....	+26	-1	-4	.....	-4
London.....	9 45 W.	51 30	30	+32	+6	-7	-5	.....
Makerstoun.....	19 25 W.	55 35	64	.....	+2	.....	.....	.....
Liege.....	12 46 E.	50 39	.....	+6	0	0	.....	.....
Louvain.....	9 26 E.	50 53	.....	-1	-3	-2	.....	.....
Brussels.....	8 6 E.	50 51	60	0	0	0	0	0
Ghent.....	5 34 E.	51 3	.....	-3	-4	+1	0	+12
Bruges.....	3 33 E.	51 18	.....	.....	-3	-3	.....	.....
Ostend.....	2 20 E.	51 14	.....	-4	-8	-8	-9	+3
Lochem.....	.....	.....	.....	-6	-15	-5	.....	-2
Utrecht.....	11 8 E.	52 5	.....	-15	-18	-6	-15	-3
Vught, Holland.....	.....	.....	.....	-24	-18	+4	-1	+3
Joppe, Holland.....	.....	.....	.....	-9	-10	-15	.....	.....
Groningen.....	16 56 E.	53 13	2	-20	-23	-18	-29	-2
Munich.....	37 5 E.	48 9	526	-20	-19	-15	.....	.....
Prague.....	48 20 E.	50 5	178	.....	-19	-3	.....	+7
Tubingen.....	26 51 E.	48 31	331	.....	-22	.....	.....	.....
Berlin.....	44 14 E.	52 31	36	.....	-20	.....	.....	.....
Stettin.....	48 54 E.	53 25	.....	-22	-20	-14	-6	.....
Jevers.....	22 16 E.	53 34	.....	-44	-23	-22	.....	.....
Gottenborg.....	38 31 E.	57 42	.....	.....	-27	.....	.....	.....
Grippenberga.....	.....	57	.....	.....	-27	.....	.....	.....
Nasinge.....	.....	59	.....	.....	-27	.....	.....	.....
Carlstadt.....	44 4 E.	59 23	49	.....	-14	.....	.....	.....
Arosia.....	.....	59 46	.....	.....	-24	.....	.....	.....
Lapland.....	.....	68 30	.....	.....	-57	.....	.....	.....
United States of America, central New York.....	.....	43	.....	.....	-30	.....	.....	.....

This table of average intervals shows how variable is the acceleration of one place over another during the different seasons of the year. This acceleration even often changes into retardation, consequently the isanthesic lines are far from remaining parallel. We therefore conclude that latitudes and longitudes are not the only and principal causes which regulate the phenomena that are engaging our attention, because these unchangeable causes could not produce different effects; it is the same with regard to altitudes, we must only consider them as intermediary agents, and we should do wrong to take them as the basis of calculations for determining the epochs of natural phenomena.<sup>a</sup> Let us see whether temperatures will give more satisfactory results. In order to facilitate the comparison I have gathered in the table (which unfortunately has not been completed for all the localities)<sup>b</sup> the average temperatures for years, seasons, and months.<sup>c</sup> I must limit myself to consulting these elements, as I have not the necessary data to compute the base of daily temperatures and particularly to take the action of the sun into consideration. This first work will perhaps make us feel the incompleteness of the system of meteorological observations adopted at present (1849) in Europe. I have also been obliged to exclude the influence of the temperature of the earth, although it is absolutely necessary to consider it, in order to treat the phenomena of vegetation in a complete manner.<sup>d</sup>

The mean temperature in winter at Brussels is 2° C. The most favored localities in comparison with it are Naples, Alais, and Polperro (near Lands End, England). I have not been able to deter-

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<sup>a</sup> It will be understood that I wish here to speak only of the action of geographical circumstances considered outside of the influence of temperature. This action has been but little studied up to the present time, but it is well worthy of our consideration. The following is what one of the most distinguished living botanists of the present time has written to me on this subject: "The distribution and extension of each species of plant over the earth shows us that the plants in general and each species as a unit are subject to organic changes dependent upon longitude and latitude. Each has a limited range; between these boundaries it has its paradise, where it thrives best. The organic changes which take place in individual plants, if one compares those that are native in different places, are such that we might presume that even their periodic phenomena must be affected. For example, all plants are stunted in height and in the number of their leaves toward their northern limit (or rather polar limit). They change their general appearance in going from east to west on the same parallel; they alter as to the extent of inflorescence and the size of flowers in going north or south on the same meridian. Now, as it is only by means of these organs that the plant vegetates in the presence of the world outside of it, it is necessary in our observations to begin with the relation of those organs, or rather the consideration of the developed organs ought to enter into our notation of their vital action. It further follows from this that we ought to study plants whose natural boundaries are known to us; these are the true barometers for vegetable life" [i. e., as the barometer is the measure of the activity of the atmospheric forces, so the natural geographic boundaries are the measures of the vital activity of plant life]. (Letter of M. de Martin's Observation of periodic phenomena, "Mem. Acad. Royal," Brussels. Vol. XVI, p. 11.)

<sup>b</sup> Further, it has sometimes been necessary to give the temperature of a neighboring locality instead of that of the place itself; thus for the temperature of Polperro I have taken that of Penzance, and the temperature of Makerstoun has been replaced by that of Edinburgh, etc.

<sup>c</sup> I have omitted these figures in my copy of Quetelet's table.—C. A.

<sup>d</sup> I should have liked to supplement this work with maps showing the principal epochs in vegetation, but the collected observations are not yet sufficiently



mine the epoch of the awakening of the plants in the first two places, but in the last mentioned the acceleration is forty-one days. This acceleration is also very great at the other stations of England, as well as at Valogne, which has also probably a sea temperature.

It has also been impossible for me to fix the time of awakening for places where the winter is the most rigorous, such as Lapland, Sweden, and the United States. We have seen, however, that there is twenty days retardation in places where the mean temperature is very little below zero. Jever seems to be an exception to this rule; but the results obtained in this place were only deduced from three observations.

The epoch of leafing corresponds, as we have said, with the end of March and the month of April, and that of the flowering with the months of May and June. The first includes the commencement of spring, the other the end of it. Thus the temperature of Brussels in spring is  $10^{\circ}$  C. The greatest variations besides are at Naples and at Alais. It is also in these places that the leafing takes place first. Venice, Parma, and Guastala are very little in advance, but the month of March and the beginning of April are scarcely any warmer than at Brussels. The difference of temperature is only felt in a marked manner in the following months. The flowering also takes place about eighteen days sooner.

Polperro, in regard to leafing, is about ten days in advance. The temperature in March is much higher than that of Brussels, while in April it is about the same. The advantage is lost in the following months, when, as regards flowering, Brussels is in advance of Polperro, as well as of the localities in England.

Brussels is about eighteen to twenty days ahead of the towns of Holland and Germany in the epoch of leafing, and is behind in the

complete to allow of undertaking such a task. The first chart would have shown by a series of lines drawn over Europe the awakening of plants for each ten days, that is to say, a first line would indicate the localities where the awakening first takes place immediately after the coldest day of the year, which with us is about the 20th of January; a second line would pass through places where the awakening is on an average ten days later, and so on. Another system of similar lines traced upon a second chart would have indicated in the same way the beginning of budding, always proceeding by intervals of ten days. We should also have made similar charts for flowering and ripening and the fall of the leaves. By comparing these charts we should be able to see at a glance the principal changes which take place in these various systems of lines. In order to complete this study we should imagine other systems of lines relating to temperatures. Thus one system would show the localities in Europe where frosts first cease, always advancing at intervals of ten days; then another system for places which, at successive intervals of ten days, and beginning from the awakening of the plants, have reached a sum total of temperatures amounting to  $183^{\circ}$  C., corresponding to the epoch of leafing; further, a third system of lines which should pass through places that, counting from the time of awakening, have successively attained the total number of degrees of temperature necessary for the flowering of plants; and so on for further systems.

The charts relating to vegetation and those relative to temperatures would, by comparing them, give much curious information. Unfortunately the observations we possess of daily temperatures are still as rare as those of the flowering. I have therefore been compelled to renounce that portion of my work.

flowering season, particularly as regards Prague, where the temperature in April, May, and June is a little higher than that of Brussels.

The retardation for stations in Sweden, the United States, and Lapland is sufficiently explained by an examination of the temperature tables, and also in regard to the epoch of ripening (fructification).

I have already had occasion to call attention elsewhere to the fact that the falling of the leaves (*effeuillage*) depends less upon the temperature of the year than upon the effects of the first cold. Thus the leaves fall sooner in the north than in the south, unless they fall sooner here on account of a season of great dryness or excessive heat.

It would be superfluous to consider the influence of the other meteorological agents when we still possess so little information as to the mode of action of the principal cause, which, in our climate, dominates in some degree all the phenomena of vegetation.

The temperature month by month at Geneva and Lausanne vary little from that observed at Brussels. The winter months there are a little colder and the vegetation is a little behind. Toward the time of ripening this retardation changes into an advance. The temperature, however, in spring and winter is no higher than that of Brussels.

Is not this advantage to be attributed to the fact that Geneva and Lausanne, having a higher elevation, enjoy purer air and a more efficient solar radiation, elements which are not indicated by the thermometer? By following the mode of calculation generally adopted one would say that the difference of latitude between Brussels and the two Swiss cities is compensated by their different altitudes. Geneva and Lausanne are  $4^{\circ} 30'$  farther south than Brussels, while their elevation averages about 420 meters greater, which shows that a degree of latitude farther north is about equal to an increase in height of 120 meters. At Munich and Gröningen the same plants flower almost simultaneously, yet their latitudes and elevations are very different. Munich is  $5^{\circ} 4'$  farther south, but is 524 meters higher. Here again a degree of south latitude nearly compensates 100 meters of elevation. It is to be regretted that we do not know the annual temperature of Gröningen. Berlin and Stettin seem to approach that locality very nearly in the natural epochs of their plants. Indeed there is very little difference in their latitudes, their elevations, and probably, also, in their temperatures.

Carlsruhe and Brussels have about the same annual temperature. The winter and early spring are a little colder in the first than in the second of these cities, consequently the vegetation is a little later; on the other hand the months of April and May are warmer, therefore, we see the vegetation changes its retardation into an advance.

Carlsruhe is about 2 degrees south of Brussels. For this reason alone vegetation should be about eight days in advance as at Paris; but on the other hand its altitude is about 300 meters greater than that of Brussels, and its vegetation should for this reason be about twelve days later. Combining the effects of these two causes, Carlsruhe would still have a retardation of more than four days, which is confirmed by experience for the first portion of the year; but in the second part we see this retardation change to an advance of fifteen days. Should we not here again remark, as was done before, that,



other things being equal, vegetation is much more active on high plateaus, where the radiation is greater, as well as in localities where the annual variations are very marked? This activity is further reinforced if the locality is near the polar regions, where the light acts almost uninterruptedly when once the awakening of the plants has taken place. In this respect Russia and Lapland present us with notable examples of this reënforcement.

Kupffer, in his "Note relating to the temperature of the soil and of the air at the limits of the region of cultivation of cereals," gives the following temperatures for the three principal boundary points of this region:

	Longi- tude.	Lati- tude.	Alti- tude.	Mean temperature.				
				Year.	Win- ter.	Spring.	Sum- mer.	Au- tumn.
	° ' /	° ' /	Feet.	° C.	° C.	° C.	° C.	° C.
Irkutsk.....	101 15	52 17	1,300	-0.25	-14.1	-0.2	+12.5	+ 0.8
Nertchinsk.....	117 1	51 18	2,100	-3.2	-21.7	-1.0	+12.9	-2.9
Archangel.....				+0.7	-10.0	-0.2	+11.5	+1.5

"A comparison of the curves for Nertchinsk, Irkutsk, and Archangel demonstrates in a striking manner," says Kupffer, "under what climatic conditions the cultivation of cereals can be carried on notwithstanding the lowness of the average annual temperature. All the curves agree together in spring and autumn, whence it results that it is especially the temperature of spring and autumn which influences the cultivation of cereals; it is in these seasons, in fact, that occur the two most important periods of the year for agriculture—the time of sowing and the time of reaping. In the cultivation of rye autumn plays a still more important part, because rye is sowed also in autumn." Kupffer calls attention in another part of his note to the fact that some kinds of farming are carried on where the soil below the surface is frozen. "Experiments in farming," he says, "have been made at Irkutsk, on a very small scale it is true, but which in many respects have been a success. This is due to the fact that the soil becomes soft on the surface and is thus capable of developing the germs received by it; its mean temperature is above zero four months in the year, which is sufficient to ripen the cereals in a country where continuity of the sunshine makes up for the weakness of solar action. Snow often falls upon the sheaves, but still they harvest them." These examples confirm what we have said in regard to annual changes of temperature. In no locality in the world are these variations greater than here; at Yakutsk the difference of temperature between the warmest and the coldest month of the year is 50.9° C.; at Irkutsk, it is 24° 1; at Nertchinsk, 39° 1; at Archangel, 28.2° C.

It might be said, it is true, that the average temperature of the year should not be considered here, not even that of the free air, so long as the plants are covered by snow to shield them, for in this case the temperature of the air does not at all represent that of the plants. In this respect the conditions of vegetation would be the same at each

locality about the time of the winter awakening, and we should particularly consider the temperature that follows after the thermometer has passed the freezing point, as well as the quantity of light radiated by the sun.

It must therefore be admitted that cold, as long as it does not destroy the life of the plant, may be more or less severe or more or less prolonged, and thus lower the average yearly temperature, without causing any marked difference in the epochs of vegetation. This reflection explains, independent of all hypothesis, that for any equable mean annual temperature the acceleration in vegetation should be in favor of localities where the annual variation is the greatest, particularly in northern countries, where the frost prevails during many months of the year and where during many of the following months the sunlight never ceases to fill the sky. Admitting the hypothesis that the action is proportional to the sum of the squares of the temperatures, the results are still more positive; for, other things being equal, the greater the annual variation the greater will be the sum of the square of the positive ordinates in the curves of temperatures.

I will now present some conclusions that one can deduce from all that precedes. I must first of all warn my readers that this work must be considered only as an attempt to solve a problem as difficult as it is interesting, the principal elements for the solution of which are still wanting.

1. A great number of factors combine to produce variations in the periodic phenomena of vegetation, the most important of which in our climate is temperature.

2. It may be estimated that the progress of vegetation is in proportion to the sum of the temperatures, or, better, to the sum of the squares of temperatures, calculated above the freezing point, starting with the epoch of the awakening of vegetation after the winter sleep.

3. The cold of winter, if it does not injure the vitality of the plant, does not cause any perceptible retardation in its future development, particularly if the ground has been covered with snow.

The effects that can be produced by the cold of winter must, however, be considered, and especially the condition of the plant when it entered upon its winter sleep, a condition which should correspond to a certain sum of acquired temperatures (or heat stored up). As to the ripening of the harvest and because plants develop under the influence of the sun, we must consult a thermometer exposed to its direct action, and not a thermometer exposed to its direct action, and not a thermometer placed in the shade, as is commonly done.

4. The temperatures at night are not comparable with those of the day as to their effects on vegetation. The quantity of light received by the plants must also be taken into consideration.

5. An increase of  $1^{\circ}$  in latitude produces about the same retardation in vegetation as an increase in elevation of 100 meters; that is to say, in our climate, a retardation of about four days.

This result should be looked upon as only a kind of average of quantities that vary during the year, the differences of latitude and elevation having scarcely any real influence further than as they produce differences of temperature.

6. The variations of temperature, other things being equal, are

favorable to vegetation, and the same may be said of high plateaus where radiation is more powerful.

7. The isanthesic lines, or lines of simultaneous flowering, do not preserve any parallelism at different periods of the year; thus, the line which shows where the lilac blooms on a given day of the month passes ten days afterwards through another series of places where the same phenomena is then occurring.

Now, the zone comprised between these two lines has not the same breadth throughout its whole extent, as would be the case with a zone between two parallels of latitude. It is not even constant, since, for example, a month later the isanthesic lines will have quite different forms, and localities that were backward as compared with others may then be in advance.

8. The falling of the leaves is a phenomenon which in our climate depends as much upon the current temperature as upon those which have preceded. It is generally controlled by the first cold of autumn.

#### FRITSCH.

Karl Fritsch (1881) gives the results of about ten years' observations of plants growing in the Botanical Garden at Vienna (1852-1861). His list of plants embraced all those recorded in the previous lists of Quetelet, Sendtner (1851), and his own, in all 1,600 species and varieties, but of which he has only used 889. The epochs observed by him, as uniformly as possible throughout the ten years, were the following:

- (1) The first visibility of the upper surface of the leaf.
- (2) The complete development of the first flower.
- (3) The complete ripening of the first fruit.
- (4) The date at which a tree or bush has lost all of its foliage.

Having endeavored in vain to establish a connection between the moisture of the air and the growth of the plant, and finding it impracticable to take account of the moisture in the earth, Fritsch resolved to reject observations made during special droughts or floods or other abnormal conditions and to consider only the sum of the average daily temperatures. These mean daily temperatures he deduced from the observations at 6 a. m. and 2 and 10 p. m., made at the Central Meteorological Institution in Vienna, where the thermometer was about 50 feet above the ground. The summation of the mean daily temperatures for comparison with phenological phenomena counts from the 1st of January to the date of the observed epoch, and omits all days whose mean temperatures are 0° Réaumur or lower than that. A comparison of the observations made on successive years on the same plant shows that the time of blossoming is uncertain by only one or two days in 96 per cent of all the plants, and the so-called "temperature" or "thermal constant" is uncertain by 3 per cent of its amount or less, in 97 per cent of all the plants. Similarly, for dates of ripen-

ing of fruits the dates of ripening as predicted by the temperature constants have an uncertainty of one or two days only in 94 per cent of the cases. In the choice of the date from which to begin taking the sum of the mean daily temperatures, it would seem that for annual plants the date of sowing the seed would be proper, but that for perennial plants the whole winter since the end of the preceding growing season would be proper; but instead of the latter, Fritsch has adopted that epoch at which the mean temperature of the day has its minimum value in the course of its annual variation, and this, combined with the ease of computation, leads him to adopt the 1st of January for all perennials. For the biennials and the annuals he would have preferred to count from the time of sowing the seed, but as the latter date was frequently not recorded and as most of the temperatures are below freezing in the early part of the year, he finds no large error introduced by adopting the 1st of January for these also, and this is very nearly equivalent to Quetelet's method of counting from the time of the permanent awakening of the activity of the plant in the spring.

In the following list I have given all of Fritsch's results, and with reference to the practical application of these figures to the prediction of similar phenomena elsewhere quote his statement that he had convinced himself in many ways that the trees and shrubs observed by him in the Botanical Gardens at Vienna blossomed at the same time as those in the open country, but for all herbs this is true to a less extent, and only in a few cases are the departures important.

Although many plants do not ripen in the short season at Vienna, yet he was able to determine their thermal constants for the date of blossoming.

In general the plants and their seed had by long cultivation in Vienna become acclimated to that locality, so that by applying Linsser's theorems to Fritsch's results they become applicable to the phenomena that would be manifested by these plants in other parts of the world.

As concerns the temperature of the soil, Fritsch states that the perennial grasses were partly shaded by trees until 1852, after which they were cultivated in a sunny spot. The annual grasses were uniformly in a sunny region, slightly inclined toward the north.

The orders or families, with the genera and species and sometimes varieties included within them, are arranged in the table as given by Fritsch, who states that it is in accordance with the natural system of Endlicher, which is generally adopted in Austria as preferable to a chronological or alphabetical. But for the convenience of American readers I have added to each of Fritsch's orders the number by which it is designated on pages 5 and 736 of Gray's Manual of

the Botany of the Northern United States, sixth edition, 1890, as revised by Watson and Coulter. These numbers will be found in the brackets following the names of the orders in the following table, e. g., [G. 129].

*Thermal constants for the blossoming and ripening of 889 plants (or the sums of the mean daily temperature above zero degrees Réaumur counting from January 1st), as determined by Karl Fritsch from observations in the Botanical Garden, in Vienna, during the years 1852-1861, inclusive.*

[See Denkschriften, Akad. Vienna, 1863, Vol. XXI.]

[See end of table for footnotes.]

Designation of plant: Order, genus, and species.	Flowering.		Ripening.	
	Date.	Constant.	Date.	Constant.
<i>I. Gramineæ [G. 129].</i>				
		° Réaum.		° Réaum.
(1) <i>Zea mays</i> L. (sown Apr. 29).....	July 20	1,082	.....	.....
(2) <i>Alopecurus pratensis</i> L.....	May 5	425	.....	.....
(3) <i>Phleum pratense</i> L. var. <i>nodosom</i> .....	June 19	981	July 28	1,595
(4) <i>Phalaris arundinacea</i> L.....	June 10	824	July 2	1,143
(5) <i>Holcus lanatus</i> L.....	June 8	812	June 28	1,111
(6) <i>Holcus mollis</i> L.....	July 2	1,144	.....	.....
(7) <i>Anthoxanthum odoratum</i> L.....	May 15	478	June 10	838
(8) <i>Panicum millaceum</i> L. (Apr. 26).....	July 7	907	July 22	1,184
(9) <i>Stipa capillata</i> L.....	June 27	1,095	July 24	1,532
(10) <i>Stipa pennata</i> L.....	June 1	698	July 1	1,154
(11) <i>Agrostis alba</i> L. ( <i>A. stolonifera</i> L. γ, <i>flagellare</i> ).....	June 29	1,091	July 16	1,376
(12) <i>Agrostis vulgaris</i> With.....	July 4	1,157	July 25	1,500
(13) <i>Calamagrostis Epigejos</i> Roth.....	July 5	1,244	July 22	1,488
(14) <i>Avena pratensis</i> L.....	May. 25	618	June 11	873
(15) <i>Avena sativa</i> L. (sown Apr. 12).....	July 5	984	July 20	1,200
(16) <i>Secalria caerulea</i> Arduin.....	Apr. 9	221	May 13	504
(17) <i>Poa compressa</i> L.....	June 16	922	July 16	1,371
(18) <i>Poa nemoralis</i> L.....	June 4	765	June 26	1,075
(19) <i>Poa pratensis</i> L.....	May 27	631	June 15	925
(20) <i>Briza media</i> L.....	June 2	760	June 17	989
(21) <i>Melica ciliata</i> L.....	June 8	856	.....	.....
(22) <i>Dactylis glomerata</i> L.....	May 27	677	June 20	999
(23) <i>Cynosurus cristatus</i> L.....	June 17	937	July 14	1,371
(24) <i>Festuca glauca</i> Lam.....	May 31	707	June 20	984
(25) <i>Festuca ovina</i> L.....	May 28	655	June 16	922
(26) <i>Festuca rubra</i> L.....	June 3	754	June 24	1,055
(27) <i>Bromus erectus</i> Huds.....	....do....	751	July 1	1,155
(28) <i>Lolium perenne</i> L.....	June 9	784	July 9	1,269
(29) <i>Triticum caninum</i> L.....	June 5	787	July 3	1,272
(30) <i>Triticum pinnatum</i> Mönch var. <i>caespitosum</i> .....	June 8	823	June 29	1,115
(31) <i>Triticum repens</i> L.....	June 18	982	July 9	1,267
(32) <i>Triticum vulgare</i> Vill. <i>hibernum</i> .....	June 2	758	July 3	1,183
(33) <i>Secale cereale</i> L. <i>hibernum</i> .....	May 25	626	June 29	1,145
(34) <i>Elymus arenarius</i> L.....	June 2	749	Aug. 19	1,990
(35) <i>Hordeum vulgare</i> L. (Apr. 12).....	June 15	648	July 16	1,150
(36) <i>Andropogon Ischaemum</i> L.....	Aug. 5	1,671	Aug. 16	2,046

*Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.*

Designation of plant: Order, genus, and species.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
II. <i>Cyperaceæ</i> [G. 128].				
		<sup>c</sup> Réaum.		<sup>o</sup> Réaum.
(37) <i>Carex distans</i> L.....	May 7	417	June 12	897
(38) <i>Carex glauca</i> Scopol.....	Apr. 26	338	...do....	889
(39) <i>Carex hirta</i> L.....	May 10	478	June 26	1,101
(40) <i>Carex hornsuhiana</i> Hoppe.....	Apr. 25	309	June 12	880
(41) <i>Carex humilis</i> Leyss.....	Apr. 1	169	.....	.....
(42) <i>Carex intermedia</i> Good.....	May 7	417	.....	.....
(43) <i>Carex maxima</i> Scop.....	May 21	542	June 26	1,070
(44) <i>Carex montana</i> L.....	Apr. 7	214	.....	.....
(45) <i>Carex paludosa</i> Good.....	May 7	449	June 27	1,002
(46) <i>Carex pilulifera</i> L.....	Apr. 12	234	.....	.....
(47) <i>Carex praecox</i> Jacq.....	Apr. 13	139	.....	.....
(48) <i>Carex Schreberi</i> Schrank.....	Apr. 25	345	.....	.....
(49) <i>Carex supina</i> Wahlb.....	Apr. 2	172	.....	.....
(50) <i>Carex tomentosa</i> L.....	Apr. 29	352	June 9	871
(51) <i>Cyperus longus</i> L.....	July 6	1,224	.....	.....
III. <i>Commelynaceæ</i> [G. 120].				
(52) <i>Tradescantia virginica</i> L. var. <i>rubra</i> .....	May 30	670	July 6	1,198
IV. <i>Alismaceæ</i> [G. 125].				
(53) <i>Alisma plantago</i> L.....	July 23	1,517	Aug. 18	2,016
V. <i>Melanthaceæ</i> [G. —; see G. 116.]				
(54) <i>Veratrum album</i> L.....	(54)	(54)	.....	.....
(55) <i>Veratrum nigrum</i> L.....	July 13	1,358	Sept. 13	2,304
(56) <i>Bulbocodium soboliferum</i> End.....	Mar. 18	107	.....	.....
(57) <i>Colchicum autumnale</i> L..... (57)	Sept. 2	2,134	June 12	903
(58) <i>Colchicum autumnale</i> L. var. <i>albiflorum</i> .....	Sept. 10	2,243	.....	.....
(59) <i>Colchicum autumnale</i> L. var. <i>subtessellatum</i> .....	Sept. 17	2,328	.....	.....
VI. <i>Liliaceæ</i> [G. 116].				
(60) <i>Erythronium dens canis</i> L.....	Mar. 31	141	.....	.....
(61) <i>Tulipa gesneriana</i> L.....	May 12	486	.....	.....
(62) <i>Tulipa oculus solis</i> St. Amand.....	May 11	470	.....	.....
(63) <i>Tulipa praecox</i> Tenor.....	Apr. 22	306	June 1	685
(64) <i>Tulipa silvestris</i> L.....	May 2	368	July 6	1,195
(65) <i>Tulipa suaveolens</i> Roth.....	Apr. 19	273	.....	.....
(66) <i>Fritillaria imperialis</i> L.....	Apr. 21	273	.....	.....
(67) <i>Fritillaria meleagris</i> L.....	...do...	284	.....	.....
(68) <i>Lilium bulbiferum</i> L.....	June 5	759	Sept. 7	2,247
(69) <i>Lilium candidum</i> L.....	June 23	1,066	.....	.....
(70) <i>Lilium croceum</i> Chaix. var. <i>saturatum</i> .....	June 3	754	Aug. 8	1,754
(71) <i>Lilium martagon</i> L.....	June 16	927	.....	.....
(72) <i>Lilium monadelphum</i> M. Bieberst.....	May 26	653	July 27	1,576
(73) <i>Funkia grandiflora</i> .....	Aug. 19	1,985	.....	.....
(74) <i>Funkia lanceifolia</i> Sieb.....	Aug. 5	1,718	.....	.....
(75) <i>Funkia ovata</i> Spreng.....	July 11	1,314	.....	.....
(76) <i>Funkia sieboldi</i> Lindl. var. <i>cucullata</i> .....	June 22	1,026	.....	.....
(77) <i>Funkia subcordata</i> Spr.....	Aug. 23	1,957	.....	.....
(78) <i>Muscari azurea</i> Fenzl.....	Mar. 16	92	.....	.....
(79) <i>Muscari botryoides</i> D. C. (later under the name <i>Muscari racemosum parviflorum</i> ). .....	Apr. 18	249	June 16	926
(80) <i>Muscari comosum</i> Mill.....	June 8	821	July 23	1,516
(81) <i>Muscari moschatum</i> Desf.....	Apr. 21	832	.....	.....



## Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
VI. <i>Liliaceæ</i> [G. 116]—Continued.				
		°Réaum.		°Réaum.
(82) <i>Muscari racemosum</i> Willd.....	Apr. 12	223	June 17	955
(83) <i>Hyacinthus amethystinus</i> L.....	May 16	542	.....	.....
(84) <i>Hyacinthus orientalis</i> L.....	Apr. 10	224	.....	.....
(85) <i>Agraphis companulata</i> Lk.....	May 10	463	.....	.....
(86) <i>Agraphis patula</i> Beh.....	do ..	457	June 26	1,091
(87) <i>Scilla amoena</i> L.....	Apr. 27	339	June 7	791
(88) <i>Scilla autumnalis</i> L.....	Sept. 7	2,376	.....	.....
(89) <i>Scilla italica</i> L.....	Apr. 21	300	.....	.....
(90) <i>Scilla pratensis</i> M. and R.....	May 20	584	.....	.....
(91) <i>Ornithogalum pyrenaicum</i> L. var. <i>narbonense</i> , mon- strosus .....	May 31	732	July 22	1,466
(92) <i>Ornithogalum umbellatum</i> L.....	May 12	470	.....	.....
(93) <i>Myogalum nutans</i> Link.....	Apr. 15	249	June 3	731
(94) <i>Puschkinia scilloides</i> Willd.....	Apr. 1	184	.....	.....
(95) <i>Allium cepa</i> L.....	July 9	1,274	.....	.....
(96) <i>Allium fistulosum</i> L. var. <i>altaicum</i> .....	May 23	608	July 1	1,169
(97) <i>Allium molly</i> L.....	June 5	785	.....	.....
(98) <i>Allium paniculatum</i> Aut. (?).....	July 23	1,487	.....	.....
(99) <i>Allium porrum</i> L.....	June 27	1,104	Aug. 28	2,076
(100) <i>Allium roseum</i> L. var. <i>bulbiferum</i> .....	May 31	718	June 28	1,120
(101) <i>Allium sativum</i> L.....	July 24	1,477	.....	.....
(102) <i>Allium schönoprasum</i> L.....	June 23	1,051	July 29	1,617
(103) <i>Allium scorodoprasum</i> L.....	July 14	1,314	.....	.....
(104) <i>Allium serotinum</i> Schleich.....	Aug. 24	2,027	Oct. 15	2,642
(105) <i>Allium ursinum</i> L.....	May 14	520	June 22	1,015
(106) <i>Allium victorialis</i> L.....	May 18	503	June 24	1,077
(107) <i>Eremerus caucasicus</i> Stev.....	May 19	567	July 2	1,180
(108) <i>Asphodelus ramosus</i> L.....	July 19	1,479	.....	.....
(109) <i>Asphodelus luteus</i> L.....	May 10	451	July 18	1,416
(110) <i>Hemerocallis flava</i> L.....	June 3	737	July 23	1,480
(111) <i>Hemerocallis fulva</i> L.....	June 23	1,042	.....	.....
(112) <i>Hemerocallis graminea</i> Andrev. var. <i>bracteosa</i> .....	May 23	605	July 14	1,490
(113) <i>Anthericum liliago</i> L.....	June 3	750	July 23	1,508
(114) <i>Anthericum ramosum</i> L.....	July 6	1,242	Aug. 29	2,096
(115) <i>Asparagus officinalis</i> L.....	May 20	572	June 25	1,068
VII. <i>Smilacæ</i> [G. —; see G. 116].				
(116) <i>Convallaria majalis</i> L.....	May 8	428	Aug. 8	1,759
(117) <i>Convallaria polygonatum</i> Desf.....	May 7	418	Aug. 5	1,699
(118) <i>Smilacina racemosa</i> Desf.....	May 18	542	.....	.....
VIII. <i>Dioscoreæ</i> [G. 115].				
(119) <i>Tamus communis</i> L.....	May 24	641	Aug. 12	1,797
IX. <i>Iridææ</i> [G. 113].				
(120) <i>Iris biflora</i> (Aut.?).....	May 9	432	.....	.....
(121) <i>Iris biglumis</i> Vahl.....	Apr. 28	359	.....	.....
(122) <i>Iris germanica</i> L. var. <i>saturata</i> .....	May 14	491	July 29	1,620
(123) <i>Iris notha</i> M. Bleb. var. <i>livescens</i> .....	June 9	853	.....	.....
(124) <i>Iris pseudacorus</i> L.....	May 28	656	.....	.....
(125) <i>Iris pumila</i> L.....	Apr. 22	296	.....	.....
(126) <i>Iris sibirica</i> L. var. <i>saturata</i> .....	May 11	578	July 28	1,547
(127) <i>Iris virginica</i> Gronov.....	June 8	746	.....	.....
(128) <i>Iris xiphium</i> L.....	June 10	868	.....	.....
(129) <i>Gladiolus communis</i> L.....	June 13	879	July 29	1,613



## Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
IX. <i>Iridæ</i> [G. 113]—Continued.				
		°Réaum.		°Réaum.
(130) <i>Gladiolus segetum</i> Ker.....	June 7	824		
(131) <i>Crocus imperati</i> Tenor.....	Oct. 21	2,730		
(132) <i>Crocus luteus</i> Lam.....	Mar. 16	103		
(133) <i>Crocus nudiflorus</i> Smith.....	Oct. 21	2,701		
(134) <i>Crocus odorus</i> Bor.....	Oct. 13	2,614		
(135) <i>Crocus pallasii</i> Goldb.....	Oct. 4	2,502		
(136) <i>Crocus præcox</i> Hock.....	Mar. 3	67		
(137) <i>Crocus sativus</i> L.....	Oct. 6	2,529		
(138) <i>Crocus sauveolens</i> Bertol.....	Mar. 18	111		
(139) <i>Crocus speciosus</i> Host.....	Sept. 23	2,406		
(140) <i>Crocus susianus</i> Ker.....	Mar. 5	81		
(141) <i>Crocus thomasi</i> Tenor.....	Oct. 13	2,543		
(142) <i>Crocus variegatus</i> Hoppe.....	Mar. 28	144		
(143) <i>Crocus vernus</i> Willd. var. <i>ilacinus</i> .....	....do....	142		
(144) <i>Crocus vernus</i> Willd., $\beta$ , <i>albiflorus</i> .....	Mar. 24	162		
(145) <i>Crocus versicolor</i> Ker.....	Mar. 21	117		
X. <i>Amaryllidæ</i> [G. 114].				
(146) <i>Galanthus nivalis</i> L.....	Mar. 3	73		
(147) <i>Galanthus plicatus</i> M. Bieb.....	Mar. 1	68		
(148) <i>Leucojum vernum</i> L.....	Mar. 20	120		
(149) <i>Sternbergia colchiciflora</i> M. et K.....	Sept. 17	2,385		
(150) <i>Sternbergia lutea</i> Schult. fil.....	Sept. 25	2,419		
(151) <i>Narcissus biflorus</i> Curt.....	May 10	464		
(152) <i>Narcissus grandiflorus</i> Hav.....	Apr. 29	366		
(153) <i>Narcissus italicus</i> Kor.....	Apr. 23	320		
(154) <i>Narcissus major</i> Curt.....	Apr. 20	265		
(155) <i>Narcissus odorus</i> L.....	Apr. 16	298		
(156) <i>Narcissus poeticus</i> L.....	Apr. 28	348		
(157) <i>Narcissus præcox</i> Tenor.....	Apr. 18	323		
(158) <i>Narcissus pseudonarcissus</i> L. var. <i>plenus</i> .....	....do....	285		
(159) <i>Narcissus seratus</i> Hav.....	....do....	218		
(160) <i>Narcissus tazeta</i> L.....	Apr. 16	311		
XI. <i>Aroidæ</i> [G. —; see G. 123].				
(161) <i>Aurum maculatum</i> L.....	May 18	548	July 14	1,377
(162) <i>Acorus calamus</i> L.....	May 27	640		
XII. <i>Typhaceæ</i> [G. 122].				
(163) <i>Typha angustifolia</i> L.....	June 14	923		
(164) <i>Typha latifolia</i> L.....	June 11	873	Oct. 26	2,737
XIII. <i>Cupressinæ</i> [G. —; see G. 107].				
(165) <i>Juniperus communis</i> L. var. <i>vulgaris</i> .....	Apr. 30	372	Aug. 26	2,025
(166) <i>Juniperus phœnicea</i> L. ♂.....	Apr. 13	190		
XIV. <i>Abietinæ</i> [G. —; see G. 107].				
(167) <i>Pinus cedrus</i> L.....	Sept. 25	2,393		
(168) <i>Pinus cembra</i> L.....	(168)	(168)		
(169) <i>Pinus laricio</i> Poir. var. <i>gibbosa</i> .....	May 20	565		
(170) <i>Pinus larix</i> L.....	Apr. 14	215		
(171) <i>Pinus nigra</i> Ait.....	May 5	393		
(172) <i>Pinus pecea</i> L.....	Apr. 28	353		
(173) <i>Pinus pumilis</i> Hænke.....	May 24	630		
(174) <i>Pinus silvestris</i> L.....	May 17	517		
(175) <i>Pinus strobus</i> L. var. <i>compressa</i> .....	(175)	(175)		
(176) <i>Pinus uncinata</i> Ramond.....	May 24	603		

## Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
XV. <i>Taxineæ</i> [G. —; see G. 107].				
(177) <i>Taxus baccata</i> L.....	Mar. 28	149	Aug. 18	1,873
(178) <i>Salisburia adiantifolia</i> Sm. ♂.....	May 11	481	.....	.....
XVI. <i>Betulaceæ</i> [G. —; see G. 103].				
(179) <i>Betula alba</i> L. var. <i>dalecarlica</i> .....	(179)	(179)	.....	.....
(180) <i>Alnus cordifolia</i> Tenor.....	Apr. 8	199	Sept. 30	2,524
(181) <i>Alnus glutinosa</i> L. var. <i>pinnatifida</i> .....	Mar. 11	97	Sept. 23	2,404
(182) <i>Alnus subcordata</i> C. H. Meyer .....	Feb. 11	55	Sept. 27	2,436
XVII. <i>Cupuliferæ</i> [G. 103].				
(183) <i>Ostrya vulgaris</i> Willd.....	May 3	381	.....	.....
(184) <i>Carpinus betulus</i> L .....	Apr. 20	279	Aug. 20	1,836
(185) <i>Carpinus orientalis</i> Lam .....	May 3	370	.....	.....
(186) <i>Corylus americana</i> Rich .....	Mar. 21	138	.....	.....
(187) <i>Corylus avellana</i> L. var. <i>globosa</i> .....	Mar. 1	72	.....	.....
(188) <i>Corylus colurna</i> Willd .....	do ..	72	.....	.....
(189) <i>Quercus alba</i> L .....	(189)	(189)	.....	.....
(190) <i>Quercus cerris</i> L .....	May 12	475	Sept. 21	2,335
(191) <i>Quercus pedunculata</i> Ehrh .....	May 6	420	Sept. 14	2,236
(192) <i>Fagus silvatica</i> L .....	May 3	380	Aug. 2	1,617
(193) <i>Fagus silvatica</i> L. var. <i>pendula</i> .....	May 7	425	.....	.....
XVIII. <i>Ulmaceæ</i> [G. —; see G. 99].				
(194) <i>Ulmus campestris</i> L. <i>montana</i> <i>tortuosa</i> .....	Mar. 30	163	May 18	540
(195) <i>Ulmus effusa</i> Willd .....	Mar. 31	162	May 20	574
XIX. <i>Celtideæ</i> [G. —; see G. 99].				
(196) <i>Celtis australis</i> L.....	Apr. 24	231	.....	.....
(197) <i>Celtis occidentalis</i> L .....	Apr. 29	350	Aug. 15	1,806
XX. <i>Moraceæ</i> [G. —; see G. 99].				
(198) <i>Morus alba</i> L. <i>morettiana</i> .....	May 15	509	June 18	970
(199) <i>Morus alba</i> L. <i>fructu nigro</i> .....	May 16	545	June 21	1,015
(200) <i>Morus scabra</i> Willd .....	May 17	549	July 8	1,280
(201) <i>Maciura aurantiaca</i> Nuttall ♀ .....	June 7	818	.....	.....
(202) <i>Broussonetia papyrifera</i> Vent. ♂ <i>cucullata</i> .....	May 11	491	.....	.....
(203) <i>Ficus carica</i> L .....	(203)	(203)	.....	.....
XXI. <i>Cannabineæ</i> [G. —; see G. 99].				
(204) <i>Humulus lupulus</i> L. ♂.....	Aug. 3	1,658	.....	.....
XXII. <i>Platanæ</i> [G. 110].				
(205) <i>Platanus occidentalis</i> L.....	May 10	467	.....	.....
(206) <i>Platanus orientalis</i> L., ♂, <i>acerifolia</i> , ♂♂, <i>grandifolia</i> ....	May 6	420	.....	.....
XXIII. <i>Salicineæ</i> [G. 104].				
(207) <i>Salix babylonica</i> L. ♀ .....	Apr. 16	262	.....	.....
(208) <i>Salix daphnoides</i> Vill. ♂ .....	Mar. 31	141	.....	.....
(209) <i>Salix purpurea</i> L.....	Apr. 14	229	May 19	525
(210) <i>Salix repens</i> L. ♂ .....	Apr. 15	238	.....	.....
(211) <i>Populus alba</i> L. ♀ <i>anglica</i> .....	Apr. 4	179	.....	.....
(212) <i>Populus balsamifera</i> L. ♂ ♂ <i>suaveolens</i> .....	Apr. 12	212	.....	.....
(213) <i>Populus canescens</i> Smith. ♂ <i>belgica</i> .....	Mar. 28	145	.....	.....
(214) <i>Populus dilatata</i> Ait. ♀ ♂ .....	Apr. 9	220	May 31	703
(215) <i>Populus græca</i> Ait. ♀ .....	Mar. 27	131	May 1	371
(216) <i>Populus nigra</i> L. ♀ .....	Apr. 12	236	May 30	683
(217) <i>Populus tremula</i> L. ♂ ♀ .....	Mar. 26	137	May 8	418

*Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.*

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
XXIV. <i>Chenopodeæ</i> [G. 87].				
(218) <i>Spinacia oleracea</i> L.....	May 12	484	June 21	1,018
(219) <i>Beta vulgaris</i> L.....	June 11	816	July 18	1,412
XXV. <i>Polygoneæ</i> [G. 89].				
(220) <i>Rheum emodi</i> Wall.....	June 4	770	.....	.....
(221) <i>Rheum hybridum</i> Ait. (later <i>R. rhaponticum</i> L.).....	May 16	494	June 21	1,021
(222) <i>Rheum palmatum</i> L. (also later <i>R. rhaponticum</i> L.)....	May 17	501	June 18	983
(223) <i>Rheum rhaponticum</i> L.....	May 11	468	June 15	921
(224) <i>Rheum undulatum</i> L.....	May 13	480	June 17	956
(225) <i>Polygonum amphibium</i> L.....	June 28	1,165	.....	.....
(226) <i>Polygonum bistorta</i> L.....	May 21	583	June 14	946
(227) <i>Polygonum fagopyrum</i> L. (sown Apr. 24).....	June 10	552	July 18	1,096
(228) <i>Rumex acetosa</i> L. ♀ ♂.....	June 1	709	July 17	1,399
(229) <i>Rumex acetosella</i> L. multifidus.....	May 27	661	.....	.....
(230) <i>Rumex crispus</i> L.....	June 4	752	July 2	1,145
(231) <i>Rumex nemolapathum</i> Ehrh.....	June 18	972	July 14	1,412
(232) <i>Rumex patientia</i> L. conferta.....	May 27	659	June 28	1,121
(233) <i>Rumex scutatus</i> L.....	May 26	627	June 20	997
XXVI. <i>Daphnoidæ</i> [G. —; see G. 94].				
(234) <i>Daphne alpina</i> L.....	May 8	432	June 21	1,011
(235) <i>Daphne laureola</i> L.....	Mar. 28	150	.....	.....
(236) <i>Daphne mezereum</i> L.....	Jan. 25	36	June 8	804
XXVII. <i>Elæagnæ</i> [G. 95].				
(237) <i>Hippophæ rhamnoides</i> L. ♂.....	May 10	383	.....	.....
(238) <i>Elæagnus hortensis</i> M. B. angustifolius.....	June 7	814	Sept. 12	2,267
XXVIII. <i>Aristolochiææ</i> [G. 91].				
(239) <i>Aristolochia clematitis</i> L.....	May 11	471	Sept. 2	2,130
(240) <i>Aristolochia sipho</i> L.....	May 21	576	.....	.....
XXIX. <i>Plantaginææ</i> [G. 83].				
(241) <i>Plantago cynops</i> L.....	May 18	534	July 9	1,298
(242) <i>Plantago lanceolata</i> L.....	May 8	425	June 28	1,157
(243) <i>Plantago media</i> L.....	May 25	620	July 16	1,373
(244) <i>Plantago saxatilis</i> M. Bleb.....	Apr. 28	359	June 29	1,148
XXX. <i>Plumbaginææ</i> [G. 60].				
(245) <i>Armeria vulgaris</i> Willd.....	May 19	566	June 21	1,036
(246) <i>Statice caspia</i> Willd.....	July 24	1,544	.....	.....
(247) <i>Statice incana</i> .....	June 14	927	July 28	1,564
(248) <i>Statice latifolia</i> Sm.....	July 22	1,476	.....	.....
(249) <i>Statice limonium</i> L.....	July 11	1,382	.....	.....
XXXI. <i>Valerianææ</i> [G. 53].				
(250) <i>Centranthus ruber</i> D. C.....	June 1	746	July 30	1,626
(251) <i>Valeriana officinalis</i> L.....	June 7	801	July 1	1,179
(252) <i>Valeriana phu</i> L.....	May 22	586	June 26	1,127
XXXII. <i>Dipsacææ</i> [G. 229].				
(253) <i>Dipsacus fullonum</i> L.....	July 11	1,313	Aug. 10	1,741
(254) <i>Dipsacus sylvestris</i> Huds.....	July 15	1,384	Aug. 11	1,792
(255) <i>Cephalaria tatarica</i> Schrad. gigantea.....	July 2	1,264	.....	.....
(256) <i>Knautia ciliata</i> Coult.....	June 4	782	.....	.....
(257) <i>Scabiosa caucasica</i> M. Bieb. heterophylla.....	July 16	1,376	Aug. 4	1,689
(258) <i>Scabiosa columbaria</i> Coult.....	June 30	1,130	July 22	1,482
(259) <i>Scabiosa ochroleuca</i> L.....	June 29	1,127	July 30	1,597
(260) <i>Scabiosa succisa</i> L.....	Aug. 4	1,677	Sept. 6	2,188

## Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
XXXIII. <i>Compositæ</i> [G. 55].				
		°Réaum.		°Réaum.
(261) <i>Eupatorium ageratoides</i> L.....	July 23	1,481	Sept. 2	2,191
(262) <i>Eupatorium cannabinum</i> L.....	July 5	1,231	Aug. 9	1,745
(263) <i>Eupatorium purpureum</i> (Aut.?) .....	Aug. 9	1,774	Sept. 19	2,351
(264) <i>Eupatorium syriacum</i> Jacq .....	Sept. 24	2,375	.....	.....
(265) <i>Tussilago petasites</i> L.....	Apr. 6	194	May 2	411
(266) <i>Tussilago farfara</i> L.....	Mar. 10	94	Apr. 17	202
(267) <i>Aster alpinus</i> L.....	May 15	479	July 2	1,155
(268) <i>Aster amellus</i> L. <i>latifolius</i> .....	Aug. 13	1,904	Oct. 4	2,503
(269) <i>Aster grandiflorus</i> L.....	Oct. 18	2,579	.....	.....
(270) <i>Aster novæ anglæ</i> Ait.....	(270)	(270)	.....	.....
(271) <i>Aster novi belgii</i> Nees .....	(271)	(271)	.....	.....
(272) <i>Aster pilosus</i> Willd.....	Sept. 12	2,248	.....	.....
(273) <i>Aster pyrenæus</i> Desf.....	Sept. 9	2,179	.....	.....
(274) <i>Erigeron acre</i> L.....	June 14	902	July 11	1,309
(275) <i>Erigeron canadensis</i> L.....	July 9	1,264	July 22	1,459
(276) <i>Solidago altissima</i> L.....	Aug. 21	1,921	Sept. 26	2,375
(277) <i>Solidago canadensis</i> L.....	Aug. 4	1,674	Sept. 7	2,178
(278) <i>Solidago confertiflora</i> D. C.....	May 24	626	June 22	1,029
(279) <i>Solidago lævigata</i> Ait.....	Oct. 15	2,613	.....	.....
(280) <i>Solidago rigida</i> Ait.....	Aug. 10	1,760	Oct. 18	2,673
(281) <i>Solidago virgaurea</i> L.....	June 26	1,082	Aug. 13	1,799
(282) <i>Linosyris vulgaris</i> Cass .....	Aug. 31	2,093	Oct. 5	2,541
(283) <i>Inula britannica</i> L.....	July 23	1,458	Aug. 26	1,968
(284) <i>Inula germanica</i> L.....	July 2	1,182	Aug. 19	1,946
(285) <i>Inula helenium</i> L.....	July 11	1,310	Aug. 11	1,804
(286) <i>Inula hirta</i> L.....	June 3	754	Aug. 13	1,797
(287) <i>Inula oculus christi</i> L.....	June 29	1,003	July 24	1,543
(288) <i>Inula salicina</i> L.....	June 22	1,026	Aug. 20	1,952
(289) <i>Inula squarrosa</i> L.....	July 8	1,253	Aug. 25	2,035
(290) <i>Inula thapsoides</i> Spr.....	July 19	1,449	Sept. 13	2,215
(291) <i>Silphium laciniatum</i> L.....	July 29	1,600	Sept. 23	2,411
(292) <i>Silphium integrifolium</i> Michx.....	July 10	1,313	Sept. 7	2,192
(293) <i>Silphium perfoliatum</i> L. <i>hornemanni</i> .....	July 5	1,232	Aug. 21	1,963
(294) <i>Silphium ternatum</i> L. <i>atropurpureum</i> .....	May 3	1,189	....do....	1,967
(295) <i>Heliopsis scabra</i> Dun.....	July 11	1,336	Sept. 1	2,066
(296) <i>Echinacea purpurea</i> Mönch .....	Aug. 2	1,653	.....	.....
(297) <i>Rudbeckia fulgida</i> Ait.....	June 25	1,049	.....	.....
(298) <i>Rudbeckia hirta</i> L.....	June 26	1,099	Aug. 2	1,651
(299) <i>Rudbeckia speciosa</i> Wenderoth .....	July 27	1,520	Sept. 21	2,382
(300) <i>Obeliscaria pinnata</i> Cass.....	July 18	1,468	.....	.....
(301) <i>Calliopsis bicolor</i> Reichb. (sown June 13) .....	Sept. 13	1,394	.....	.....
(302) <i>Coreopsis lanceolata</i> L.....	June 22	1,026	July 25	1,403
(303) <i>Helianthus annuus</i> L.....	Aug. 16	1,511	Sept. 15	1,947
(304) <i>Helianthus giganteus</i> L..... (304)	Aug. 13	1,783	.....	.....
(305) <i>Helianthus grosse-serratus</i> Mert .....	Oct. 2	2,426	.....	.....
(306) <i>Helianthus multiflorus</i> L.....	July 22	1,472	Sept. 19	2,303
(307) <i>Helianthus orygalis</i> D. C.....	Sept. 15	2,299	.....	.....
(308) <i>Helianthus tuberosus</i> L.....	(308)	(308)	.....	.....
(309) <i>Helianthus tracheliformis</i> Willd .....	Aug. 6	1,712	.....	.....
(310) <i>Bidens tripartita</i> L.....	Aug. 25	2,005	Sept. 26	2,437
(311) <i>Verbesina phætusa</i> Cassin .....	Oct. 10	2,508	.....	.....
(312) <i>Tagetes patula</i> L. (sown June 13) .....	Aug. 10	886	.....	.....
(313) <i>Gaillardia aristata</i> Pursh .....	June 9	833	July 12	1,334

## Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
XXXIII. <i>Compositæ</i> [G. 55]—Continued.				
		°Réaum.		°Réaum.
(314) <i>Gaillardia drummondii</i> D. C.....	June 5	800	.....	.....
(315) <i>Gaillardia lanceolata</i> Mich.....	June 4	778	July 12	1,331
(316) <i>Gaillardia pulchella</i> Fougér.....	June 5	778	July 8	1,279
(317) <i>Helenium autumnale</i> L. <i>serratifolium</i> .....	Aug. 1	1,655	Aug. 31	2,071
(318) <i>Anthemis nobilis</i> L.....	June 27	1,108	July 28	1,606
(319) <i>Anthemis tinctoria</i> L. <i>pallida</i> .....	June 11	856	July 25	1,515
(320) <i>Achillea magna</i> Hænke.....	June 12	830	Aug. 10	1,770
(321) <i>Achillea millefolium</i> L.....	June 21	1,006	Aug. 12	1,807
(322) <i>Achillea nobilis</i> L.....	June 17	908	July 28	1,599
(323) <i>Achillea tomentosa</i> L.....	May 24	611	July 4	1,202
(324) <i>Anacyclus pyrethrum</i> D. C.....	May 20	567	.....	.....
(325) <i>Ptarmica alpina</i> D. C.....	June 23	1,002	Aug. 24	2,018
(326) <i>Ptarmica vulgaris</i> D. C.....	do ..	1,037	Aug. 21	1,968
(327) <i>Matricaria chamomilla</i> L.....	May 19	556	July 19	981
(328) <i>Pyrethrum chinense</i> Sab.....	Oct. 25	2,696	.....	.....
(329) <i>Pyrethrum parthenium</i> L.....	June 9	845	July 17	1,427
(330) <i>Chrysanthemum coronarium</i> L. (sown June 17).....	Aug. 25	1,117	.....	.....
(331) <i>Artemisia absinthium</i> L.....	Aug. 10	1,803	.....	.....
(332) <i>Artemisia vulgaris</i> L. <i>coarctata</i> .....	July 19	1,416	Sept. 16	2,377
(333) <i>Tanacetum leucanthemum</i> Schultz.....	May 21	565	June 27	1,092
(334) <i>Tanacetum vulgare</i> L.....	July 17	1,422	Aug. 21	1,988
(335) <i>Doronicum pardalianthes</i> L.....	May 6	413	May 29	693
(336) <i>Cacalia suaveolens</i> L.....	July 25	1,510	Aug. 30	2,066
(337) <i>Senecio aquaticus</i> Huds.....	June 5	753	Sept. 12	1,307
(338) <i>Senecio coriaceus</i> Ait.....	June 23	1,045	July 15	1,379
(339) <i>Senecio jacobæa</i> L.....	July 27	1,518	Aug. 22	1,918
(340) <i>Senecio jacobæa</i> L. <i>campestris</i> .....	June 7	830	July 13	1,305
(341) <i>Echinops ritro</i> L. <i>polycephala</i> .....	July 22	1,467	Aug. 20	1,963
(342) <i>Echinops sphaerocephalus</i> L.....	July 9	1,285	Aug. 23	2,002
(343) <i>Haplotaxis albescens</i> D. C.....	July 28	1,640	.....	.....
(344) <i>Carlina vulgaris</i> L.....	do ..	1,612	Sept. 6	2,186
(345) <i>Centaurea aspera</i> L.....	June 27	1,086	.....	.....
(346) <i>Centaurea calocephala</i> D. C. <i>mixta</i> .....	June 23	1,057	July 22	1,489
(347) <i>Centaurea dealbata</i> Willd. var. <i>major</i> .....	May 24	632	June 15	926
(348) <i>Centaurea Jacea</i> L. <i>lacera</i> , <i>incana</i> .....	July 13	1,351	.....	.....
(349) <i>Centaurea lagdunensis</i> ? (var. of <i>C. montana</i> ?).....	May 2	575	.....	.....
(350) <i>Centaurea rupestris</i> L. <i>aculeosa</i> .....	June 17	952	July 18	1,414
(351) <i>Cnicus benedictus</i> L. (sown May 5).....	July 9	896	.....	.....
(352) <i>Carthamus tinctorius</i> L. (sown May 4).....	July 21	1,071	.....	.....
(353) <i>Onopordon acanthium</i> L. <i>horridum</i> .....	July 7	1,215	Aug. 7	1,722
(354) <i>Onopordon virens</i> D. C.....	June 27	1,088	July 30	1,590
(355) <i>Cynara cardunculus</i> L.....	July 26	1,551	Sept. 14	2,273
(356) <i>Cynara scolymus</i> L.....	July 31	1,624	Sept. 28	2,442
(357) <i>Carduus crispus</i> L.....	July 10	1,276	Aug. 4	1,690
(358) <i>Cirsium acaule</i> All.....	July 13	1,321	Aug. 9	1,761
(359) <i>Cirsium bulbosum</i> D. C.....	June 18	970	July 6	1,251
(360) <i>Cirsium lanceolatum</i> Scop.....	July 24	1,522	Aug. 21	1,983
(361) <i>Cirsium pannonicum</i> D. C.....	July 7	1,247	July 22	1,496
(362) <i>Cirsium pratense</i> D. C.....	July 18	1,400	.....	.....
(363) <i>Lappa major</i> Gärtn.....	July 15	1,370	Aug. 21	1,948
(364) <i>Lappa tomentosa</i> Lam.....	July 14	1,364	do ..	1,941
(365) <i>Rhaponticum cinaroides</i> Lessing.....	July 8	1,301	.....	.....
(366) <i>Rhaponticum pulchrum</i> Fischer et Meyer.....	June 13	909	July 14	1,343

## Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
XXXIII.— <i>Compositæ</i> [G. 55]—Continued.				
		°Réaum.		°Réaum.
(367) <i>Serratula coronata</i> (L.?)	July 27	1,550	.....	.....
(368) <i>Serratula tinctoria</i> L.	....do....	1,515	Aug. 21	1,950
(369) <i>Catananche caerulea</i> L.	June 22	999	Aug. 7	1,709
(370) <i>Cichorium intybus</i> L.	June 24	1,065	July 25	1,544
(371) <i>Hypochaeris radicata</i> L.	June 7	817	June 27	1,103
(372) <i>Podospermum jacquinianum</i> , Koch	May 14	503	.....	.....
(373) <i>Tragopogon porrifolius</i> L.	May 31	698	June 16	958
(374) <i>Tragopogon pratensis</i> L.	May 22	596	July 16	975
(375) <i>Scorzonera austriaca</i> L.	May 13	486	.....	.....
(376) <i>Scorzonera hispanica</i> L.	May 27	657	June 25	1,070
(377) <i>Picridium tingitanum</i> Desf. (sown June 18)	Aug. 12	826	Sept. 9	1,216
(378) <i>Lactuca sativa</i> L.	July 5	1,182	July 26	1,582
(379) <i>Lactuca virosa</i> L.	June 27	1,110	July 18	1,418
(380) <i>Chondrilla juncea</i> L.	July 22	1,534	.....	.....
(381) <i>Taraxacum dens leonis</i> Desf.	Apr. 21	299	May 8	443
(382) <i>Hieracium aurantiacum</i> L.	May 30	675	June 20	1,019
(383) <i>Hieracium murorum</i> L.	May 19	622	.....	.....
(384) <i>Hieracium pratense</i> Tausch.	May 27	659	June 12	909
(385) <i>Hieracium saxatile</i> Jacq.	July 13	1,358	July 30	1,625
(386) <i>Hieracium umbellatum</i> L. <i>pectinatum</i>	Aug. 1	1,732	Aug. 23	2,010
(387) <i>Hieracium virosum</i> Pallas.	July 12	1,350	Aug. 11	1,821
XXXIV. <i>Lobeliaceæ</i> [G. 56].				
(388) <i>Lobelia syphilitica</i> L.	July 23	1,501	.....	.....
XXXV. <i>Campanulaceæ</i> [G. 57].				
(389) <i>Phyteuma spicatum</i> L.	May 23	589	July 10	1,306
(390) <i>Campanula albanicaefolia</i> Willd.	June 23	1,050	.....	.....
(391) <i>Campanula bononiensis</i> L. <i>ruthenica</i> .	July 2	1,199	.....	.....
(392) <i>Campanula caespitosa</i> Scop. <i>alba</i> .	July 4	1,210	.....	.....
(393) <i>Campanula glomerata</i> L.	....do....	1,201	.....	.....
(394) <i>Campanula media</i> L.	June 11	861	.....	.....
(395) <i>Campanula pyramidalis</i> L.	July 23	1,543	.....	.....
(396) <i>Campanula rapunculus</i> L.	June 4	781	July 9	1,297
(397) <i>Campanula trachelium</i> (L.)	July 5	1,222	Aug. 24	2,030
XXXVI. <i>Rubiaceæ</i> [G. 52].				
(398) <i>Galium mollugo</i> L.	June 2	708	July 21	1,462
(399) <i>Galium verum</i> L. <i>brachyphyllum</i>	June 29	1,149	.....	.....
(400) <i>Rubia tinctorum</i> L.	June 28	1,118	Aug. 18	1,876
(401) <i>Asperula galloides</i> M. Bieb.	July 2	1,172	Aug. 23	2,050
(402) <i>Asperula odorata</i> L.	May 7	453	.....	.....
(403) <i>Asperula tinctoria</i> L.	May 26	651	July 21	1,480
(404) <i>Cephalanthus occidentalis</i> R. S.	July 21	1,513	.....	.....
XXXVII. <i>Lonicereæ</i> [G. —; see G. 51].				
(405) <i>Lonicera caprifolium</i> L.	June 1	701	.....	.....
(406) <i>Lonicera grata</i> Ait.	June 16	946	.....	.....
(407) <i>Lonicera iberica</i> M. Bieb.	June 5	783	.....	.....
(408) <i>Lonicera periclymenum</i> L.	June 11	863	July 28	1,592
(409) <i>Lonicera tatarica</i> L. <i>pallida</i>	May 6	414	June 22	1,076
(410) <i>Lonicera xylosteum</i> L.	May 7	421	June 28	1,102
(411) <i>Viburnum lantana</i> L.	May 3	389	Aug. 2	1,662

*Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.*

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
XXXVII. <i>Lonicereæ</i> [G. —; see G. 51].—Continued.				
		°Réaum.		°Réaum.
(412) <i>Viburnum opulus</i> L.....	May 17	507	July 23	1,482
(413) <i>Sambucus ebulus</i> L.....	June 23	1,042	Aug. 11	1,817
(414) <i>Sambucus nigra</i> L.....	May 22	579	Aug. 7	1,692
(415) <i>Sambucus racemosa</i> L.....	May 1	350	June 22	1,004
XXXVIII. <i>Oleaceæ</i> [G. 65].				
(416) <i>Ligustrum vulgare</i> L.....	June 3	746	Sept. 9	2,254
(417) <i>Fraxinus excelsior</i> L.....	Apr. 14	248	July 23	1,443
(418) <i>Fraxinus excelsior</i> L. <i>aurea</i> .....	do	277	May 22	590
(419) <i>Fraxinus excelsior</i> L. <i>pendula</i> .....	Apr. 20	296	July 11	1,281
(420) <i>Fraxinus ornus</i> L.....	May 18	537		
(421) <i>Fraxinus tamariscifolia</i> Vahl.....	Apr. 8	222		
(422) <i>Syringa josikea</i> Jacq.....	May 21	597		
(423) <i>Syringa persica</i> L.....	May 12	478		
(424) <i>Syringa vulgaris</i> L.....	May 6	424	Aug. 26	2,014
XXXIX. <i>Apocynaceæ</i> [G. 66].				
(425) <i>Vinca herbacea</i> M. et K.....	Apr. 26	337		
(426) <i>Vinca minor</i> L. <i>variegata</i> .....	Apr. 16	265		
XL. <i>Asclepiadaceæ</i> [G. 67].				
(427) <i>Periploca græca</i> L.....	June 6	798		
(428) <i>Vincetoxicum fuscatum</i> Endl.....	May 24	620	Aug. 12	1,816
(429) <i>Vincetoxicum nigrum</i> Mönch.....	June 2	719	Aug. 20	1,935
(430) <i>Vincetoxicum officinale</i> Mönch.....	May 16	529	Aug. 24	1,947
(431) <i>Asclepias syriaca</i> L.....	June 24	1,044		
XLI. <i>Gentianeæ</i> [G. 69].				
(432) <i>Menyanthes trifoliata</i> L.....	Apr. 29	358		
XLII. <i>Labiataæ</i> [G. 82].				
(433) <i>Lavandula spica</i> D. C.....	Aug. 4	1,696	Sept. 24	2,430
(434) <i>Lavandula vera</i> D. C.....	June 26	1,093	Aug. 3	1,650
(435) <i>Mentha crispa</i> L.....	July 14	1,368		
(436) <i>Mentha piperita</i> L.....	July 22	1,496		
(437) <i>Mentha pulegium</i> L.....	July 21	1,475		
(438) <i>Mentha rotundifolia</i> L.....	July 23	1,488		
(439) <i>Lycopus europæus</i> L.....	July 5	1,247	Aug. 19	1,931
(440) <i>Salvia argentea</i> L.....	June 10	879	July 13	1,357
(441) <i>Salvia austriaca</i> L.....	May 22	606	June 15	929
(442) <i>Salvia glutinosa</i> L.....	July 27	1,559	Aug. 29	2,052
(443) <i>Salvia officinalis</i> L.....	June 1	722	July 6	1,241
(444) <i>Salvia pischeri</i> Torr.....	Oct. 13	2,616		
(445) <i>Salvia pratensis</i> L.....	May 16	526	June 9	823
(446) <i>Salvia sclarea</i> Jacq.....	June 18	958	July 27	1,562
(447) <i>Salvia silvestris</i> L.....	May 23	608	June 21	1,015
(448) <i>Monarda fistulosa</i> L.....	July 10	1,294	Aug. 23	1,960
(449) <i>Origanum vulgare</i> L.....	June 22	1,028	Aug. 9	1,736
(450) <i>Thymus serpyllum</i> L. <i>vulgaris</i> .....	May 22	589	June 16	1,018
(451) <i>Thymus vulgaris</i> L.....	June 1	721		
(452) <i>Hyssopus officinalis</i> L.....	July 1	1,164	Aug. 4	1,712
(453) <i>Calamintha clinopodium</i> Benth.....	June 20	1,003		
(454) <i>Calamintha grandiflora</i> Mönch.....	June 6	791		
(455) <i>Calamintha nepeta</i> K. et Hoffm. var. <i>albiflora</i> .....	July 2	1,183	Aug. 17	1,875



## Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
XLII. <i>Labiatae</i> [G. 82]—Continued.				
		°Réaum.		°Réaum.
(456) <i>Melissa officinalis</i> L.....	July 9	1,267	Aug. 6	1,720
(457) <i>Prunella grandiflora</i> Mönch.....	June 16	933	July 18	1,442
(458) <i>Prunella vulgaris</i> L.....	June 22	1,017	July 17	1,379
(459) <i>Scutellaria alpina</i> L. <i>lupulina purpurascens</i> .....	May 22	605	June 22	1,049
(460) <i>Scutellaria galericulata</i> L.....	July 1	1,166	.....	.....
(461) <i>Nepeta cataria</i> L.....	June 25	1,058	July 25	1,536
(462) <i>Nepeta mussini</i> M. Bieb. var. <i>salviaefolia</i> .....	Apr. 28	379	.....	.....
(463) <i>Nepeta glechoma</i> Benth.....	Apr. 10	224	May 31	698
(464) <i>Dracocephalum austriacum</i> L.....	May 24	613	June 21	1,053
(465) <i>Melittis melissophyllum</i> L.....	May 19	575	.....	.....
(466) <i>Physostegia speciosa</i> Sweet.....	July 13	1,321	Aug. 8	1,746
(467) <i>Lamium orvala</i> L.....	May 4	400	June 2	763
(468) <i>Leonurus cardiaca</i> L.....	June 10	839	July 19	1,443
(469) <i>Stachys alpina</i> L. var. <i>intermedia</i> .....	June 24	1,052	July 27	1,582
(470) <i>Stachys germanica</i> L. var. <i>oblongifolia</i> .....	June 10	838	July 23	1,529
(471) <i>Betonica officinalis</i> L.....	June 30	1,149	Aug. 7	1,805
(472) <i>Sideritis scordioloides</i> L.....	June 5	770	July 9	1,285
(473) <i>Marrubium vulgare</i> L.....	June 7	787	July 17	1,417
(474) <i>Ballota nigra</i> L.....	July 1	1,185	Aug. 10	1,766
(475) <i>Phlomis tuberosa</i> L.....	June 1	722	July 12	1,311
(476) <i>Teucrium chamædrys</i> L.....	June 22	1,036	Aug. 10	1,796
(477) <i>Teucrium montanum</i> L.....	June 23	1,045	Aug. 5	1,742
(478) <i>Teucrium scordium</i> L.....	July 7	1,273	.....	.....
(479) <i>Ajuga genevensis</i> L.....	May 12	483	.....	.....
(480) <i>Ajuga reptans</i> L.....	May 14	460	.....	.....
XLIII. <i>Globulariæ</i> [G. —; see G. 1].				
(481) <i>Globularia vulgaris</i> L.....	May 4	397	July 7	1,253
XLIV. <i>Asperifoliæ</i> [G. —; see G. 72].				
(482) <i>Cerinthæ minor</i> L.....	Apr. 28	357	May 29	701
(483) <i>Echium vulgare</i> L.....	June 5	786	.....	.....
(484) <i>Pulmonaria officinalis</i> L.....	Apr. 10	207	.....	.....
(485) <i>Pulmonaria mollis</i> Wolff.....	Apr. 8	207	.....	.....
(486) <i>Lithospermum purpureoceruleum</i> L.....	May 16	554	July 17	1,382
(487) <i>Anchusa officinalis</i> L.....	May 24	599	June 27	1,056
(488) <i>Myosotis palustris</i> Roth.....	May 30	694	.....	.....
(489) <i>Symphytum officinale</i> L.....	May 25	619	June 27	1,093
XLV. <i>Convolvulacæ</i> [G. 73].				
(490) <i>Calystegia sepium</i> R. B.....	June 11	863	July 20	1,462
(491) <i>Convolvulus tricolor</i> L. (sown June 18).....	Aug. 27	1,063	.....	.....
(492) <i>Pharbitis hispida</i> Choix. (sown June 18).....	June 13	855	.....	.....
XLVI. <i>Polemoniaceæ</i> [G. 70].				
(493) <i>Phlox cordata</i> Elliot <i>grandiflora</i> .....	July 21	1,486	.....	.....
(494) <i>Phlox speciosa</i> Pursh.....	Aug. 14	1,890	.....	.....
(495) <i>Polemonium cæruleum</i> L.....	May 26	636	June 28	1,103
XLVII. <i>Solanacæ</i> [G. 74].				
(496) <i>Datura stramonium</i> L.....	June 18	626	Aug. 4	1,332
(497) <i>Hyoscyamus niger</i> L.....	May 16	533	July 31	1,638
(498) <i>Physalis alkekengi</i> L.....	May 30	719	Aug. 11	1,755
(499) <i>Solanum dulcamara</i> L.....	July 17	1,437	Oct. 1	2,474
(500) <i>Solanum nigrum</i> L. (sown Apr. 26).....	July 4	867	Aug. 31	1,744
(501) <i>Atropa belladonna</i> L.....	May 27	661	July 19	1,458

## Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
XLVIII. <i>Scrophularinæ</i> [G. 75].				
		°Réaum.		°Réaum.
(502) <i>Verbascum gnaphaloides</i> M. Bieb .....	July 26	1,533	.....	.....
(503) <i>Verbascum lychnitis</i> L. fl. rub. lanatum floccosum .....	June 8	825	.....	.....
(504) <i>Verbascum nigrum</i> L. lasianthum .....	May 25	628	July 25	1,504
(505) <i>Verbascum phlomoides</i> L. ....	June 19	1,001	Aug. 12	1,832
(506) <i>Verbascum phœniceum</i> L. ....	May 16	510	July 13	1,385
(507) <i>Verbascum speciosum</i> L. genuinum .....	June 20	1,074	.....	.....
(508) <i>Verbascum thapsus</i> L. ....	June 26	1,086	Aug. 13	1,842
(509) <i>Scrophularia nodosa</i> L. ....	May 28	652	July 12	1,304
(510) <i>Linaria genistifolia</i> Mill .....	July 1	1,188	Aug. 6	1,715
(511) <i>Linaria vulgaris</i> Mill .....	July 8	1,220	Aug. 8	1,756
(512) <i>Antirrhinum majus</i> L. ....	June 6	816	.....	.....
(513) <i>Pentstemon barbatus</i> Benth. robustum .....	July 4	1,227	Sept. 8	2,162
(514) <i>Pentstemon digitalis</i> Nutt .....	June 11	865	Sept. 5	2,158
(515) <i>Pentstemon pubescens</i> Poland .....	May 30	690	Aug. 3	1,688
(516) <i>Digitalis lutea</i> L. ....	June 9	845	Aug. 1	1,653
(517) <i>Digitalis purpurea</i> L. ....	June 6	772	July 20	1,482
(518) <i>Paulownia imperialis</i> Siebold .....	(518)	(518)	.....	.....
(519) <i>Dodartia orientalis</i> L. ....	June 6	797	.....	.....
(520) <i>Gratiola officinalis</i> L. ....	June 4	758	Aug. 8	1,730
(521) <i>Veronica austriaca</i> L. var. pinnatifida .....	May 17	504	July 12	1,312
(522) <i>Veronica latifolia</i> L. var. major .....	June 4	761	Aug. 2	1,673
(523) <i>Veronica officinalis</i> L. ....	May 16	528	June 26	1,098
(524) <i>Veronica spicata</i> L. var. cristata .....	July 5	1,226	.....	.....
XLIX. <i>Acanthaceæ</i> [G. 80].				
(525) <i>Acanthus spinosus</i> L. ....	June 19	985	Aug. 19	1,943
L. <i>Bignoniaceæ</i> [G. 78].				
(526) <i>Catalpa syriacæfolia</i> Sims .....	July 3	1,193	Oct. 4	2,666
(527) <i>Tecoma grandiflora</i> Sweet .....	July 28	1,602	.....	.....
(528) <i>Tecoma radicans</i> Juss var. flammea .....	Aug. 8	1,746	.....	.....
LI. <i>Primulaceæ</i> [G. 61].				
(529) <i>Primula auricula</i> L. ....	Mar. 15	113	.....	.....
(530) <i>Cyclamen europæum</i> L. ....	July 18	1,437	.....	.....
(531) <i>Dodecatheon meadia</i> L. ....	May 13	453	June 29	1,093
(532) <i>Lysimachia nummularia</i> L. ....	June 21	1,021	.....	.....
(533) <i>Lysimachia punctata</i> L. ....	June 16	926	.....	.....
LII. <i>Ebenaceæ</i> G. [65].				
(534) <i>Diospyros lotus</i> L. ♂ .....	June 16	980	.....	.....
LIII. <i>Ericaceæ</i> [G. 58].				
(535) <i>Erica carnea</i> L. ....	Mar. 10	80	.....	.....
LIV. <i>Umbelliferæ</i> [G. 48].				
(536) <i>Eryngium amethystinum</i> W. and K. ....	July 14	1,380	Aug. 29	2,073
(537) <i>Eryngium maritimum</i> .....	July 15	1,388	Aug. 28	2,059
(538) <i>Eryngium planum</i> L. ....	July 3	1,189	Aug. 5	1,645
(539) <i>Cicuta virosa</i> L. ....	June 25	1,025	.....	.....
(540) <i>Apium graveolens</i> L. ....	June 11	885	Aug. 16	1,867
(541) <i>Petroselinum sativum</i> Hoffm. ....	June 20	989	Aug. 11	1,779
(542) <i>Carum carui</i> L. ....	Apr. 25	338	June 12	884
(543) <i>Sium sisarum</i> L. ....	July 20	1,436	.....	.....
(544) <i>Bupleurum ranunculoides</i> L. v. elatium .....	June 4	751	July 21	1,486

## Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and plant.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
LIV. <i>Umbelliferae</i> [G. 48]—Continued.				
		° Réaum.		° Réaum.
(545) <i>Oenanthe phellandrium</i> Lam.....	June 20	984		
(546) <i>Æthusa cynapium</i> L.....	July 2	1,173	Aug. 19	1,936
(547) <i>Foeniculum vulgare</i> Gärtn.....	June 27	1,114	Aug. 20	1,920
(548) <i>Seseli campestre</i> Besser.....	June 15	910		
(549) <i>Libanotis vulgaris</i> D. C.....	June 27	1,113	Aug. 21	1,965
(550) <i>Levisticum officinale</i> Koch.....	June 10	858	July 17	1,395
(551) <i>Archangelica officinalis</i> Hoffm.....	June 6	769	Aug. 15	1,384
(552) <i>Peucedanum cervarium</i> Cass.....	July 17	1,417	Aug. 25	2,007
(553) <i>Peucedanum imperatorium</i> Endl.....	May 29	703	June 30	1,186
(554) <i>Peucedanum officinale</i> L.....	July 2	1,176	Aug. 13	1,797
(555) <i>Pastinaca sativa</i> L.....	July 9	1,272	Aug. 9	1,761
(556) <i>Daucus carota</i> L.....	June 18	973	Aug. 2	1,628
(557) <i>Anthriscus cerefolium</i> Hoffm.....	June 11	440		
(558) <i>Anthriscus silvestris</i> Hoffm. var. <i>pilosula</i> .....	May 4	407	June 16	914
(559) <i>Conium maculatum</i> L.....	June 19	1,010	Aug. 2	1,688
LV. <i>Ampelidæ</i> [G. —; see G. 28].				
(560) <i>Cissus hederacea</i> Pers.....	June 24	1,057	Aug. 27	2,050
(561) <i>Vitis vinifera</i> L. var. <i>alexandrina</i> .....	June 7	805	Sept. 5	2,172
LVI. <i>Cornæ</i> [G. 50].				
(562) <i>Cornus alba</i> L.....	May 17	513	July 4	1,216
(563) <i>Cornus mas</i> L.....	Mar. 29	145	Aug. 19	1,907
(564) <i>Cornus sanguinea</i> L.....	June 1	729	Aug. 16	1,864
LVII. <i>Crassulacæ</i> [G. 36].				
(565) <i>Sedum acre</i> L.....	May 31	682		
(566) <i>Sedum album</i> L.....	June 25	1,072	Aug. 3	1,637
(567) <i>Sedum latifolium</i> Bertol.....	Aug. 6	1,726	Sept. 12	2,313
(568) <i>Sedum reflexum</i> L. var. <i>recurvatum</i> .....	June 20	1,005	Aug. 2	1,679
(569) <i>Sedum sexangulare</i> L.....	June 11	871	July 26	1,510
(570) <i>Sedum Sieboldii</i> Hort.....	Oct. 11	2,588		
LVIII. <i>Saxifragacæ</i> [G. 35].				
(571) <i>Saxifraga crassifolia</i> L. var. <i>obovata</i> .....	Apr. 19	290		
(572) <i>Saxifraga cordifolia</i> Haw.....	Apr. 13	256		
(573) <i>Heuchera americana</i> L.....	May 26	657	July 14	1,345
LIX. <i>Ribesiacæ</i> [G. —; see G. 35].				
(574) <i>Ribes alpinum</i> L.....	Apr. 17	237		
(575) <i>Ribes aureum</i> Pursh. var. <i>sanguineum</i> .....	do	264	June 29	1,108
(576) <i>Ribes grossularia</i> L.....	Apr. 10	226		
(577) <i>Ribes nigrum</i> L.....	(577)	(577)		
(578) <i>Ribes rubrum</i> L.....	Apr. 18	269	June 8	868
(579) <i>Robsonia speciosa</i> .....	May 15	469		
LX. <i>Magnoliacæ</i> [G. 2].				
(580) <i>Magnolia acuminata</i> L.....	(580)	(580)		
(581) <i>Liriodendron tulipifera</i> L.....	(581)	(581)		
LXI. <i>Dilleniaceæ</i> [G. —; see G. 1].				
(582) <i>Actæa spicata</i> L.....	May 7	426		

## Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plants: order, genus, and species.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
LXII. <i>Ranunculaceæ</i> [G. 1].				
		°Réaum.		°Réaum.
(583) <i>Clematis augustifolia</i> Jacq. <i>lasiantha</i> .....	June 3	745	.....	.....
(584) <i>Clematis erecta</i> Allion. <i>Clematis recta</i> L.....	June 4	765	.....	.....
(585) <i>Clematis flammula</i> L. var. <i>vulgaris</i> .....	July 21	1,476	.....	.....
(586) <i>Clematis integrifolia</i> L. var. <i>elongata</i> .....	May 31	701	July 18	1,405
(587) <i>Clematis orientalis</i> L.....	Aug. 24	1,988	.....	.....
(588) <i>Clematis sibirica</i> L., <i>Atragene sibirica</i> .....	Apr. 22	313	.....	.....
(589) <i>Clematis virginiana</i> L.....	Aug. 12	1,857	.....	.....
(590) <i>Clematis vitalba</i> L. var. <i>bannatica</i> .....	Aug. 2	1,671	.....	.....
(591) <i>Atragene alpina</i> L.....	May 4	398	July 14	1,329
(592) <i>Thalictrum aquilegifolium</i> L.....	May 22	582	July 30	1,598
(593) <i>Thalictrum flavum</i> L.....	July 3	1,142	.....	.....
(594) <i>Thalictrum minus</i> L.....	May 23	616	July 13	1,395
(595) <i>Anemone japonica</i> S. et Zucc.....	Aug. 19	1,869	Sept. 7	2,236
(596) <i>Anemone nemorosa</i> L.....	Apr. 10	224	.....	.....
(597) <i>Anemone pratensis</i> L.....	Apr. 6	200	May 23	606
(598) <i>Anemone pulsatilla</i> L.....	Mar. 29	151	.....	.....
(599) <i>Anemone ranunculoides</i> L.....	Apr. 17	275	.....	.....
(600) <i>Anemone silvestris</i> L. var. <i>minor</i> .....	May 6	413	June 14	918
(601) <i>Anemone virginiana</i> L. var. <i>angustifolia</i> .....	June 7	791	Aug. 13	1,825
(602) <i>Hepatica angulosa</i> Lam.....	Mar. 6	78	.....	.....
(603) <i>Hepatica triloba</i> Chaix.....	Mar. 10	118	May 24	647
(604) <i>Adonis vernalis</i> L.....	Apr. 16	260	.....	.....
(605) <i>Ranunculus acris</i> L. var. <i>silvaticus</i> .....	May 14	499	June 17	974
(606) <i>Ranunculus nemorosus</i> D. C.....	May 20	549	June 27	1,086
(607) <i>Ficaria ranunculoides</i> Roth. <i>variegata</i> .....	Apr. 4	191	.....	.....
(608) <i>Caltha palustris</i> L.....	Apr. 28	349	July 4	1,180
(609) <i>Eranthis hiemalis</i> Salisb.....	Feb. 27	79	May 16	527
(610) <i>Helleborus niger</i> L.....	Oct. 19	2,677	.....	.....
(611) <i>Helleborus odorus</i> W. Kit.....	Mar. 24	136	.....	.....
(612) <i>Helleborus purpurascens</i> W. Kit.....	Mar. 28	142	.....	.....
(613) <i>Helleborus viridis</i> L.....	Apr. 10	197	June 17	893
(614) <i>Aquilegia atrata</i> Koch.....	May 5	341	June 18	965
(615) <i>Aquilegia atropurpurea</i> Willd.....	Apr. 16	282	May 29	727
(616) <i>Aquilegia glandulosa</i> Mönch.....	May 20	562	June 28	1,133
(617) <i>Aquilegia vulgaris</i> L. var. <i>rosea</i> .....	May 18	511	....do....	1,094
(618) <i>Delphinium consolida</i> L.....	May 26	663	July 26	1,349
(619) <i>Delphinium grandiflorum</i> L.....	June 28	1,135	Aug. 8	1,707
(620) <i>Delphinium intermedium</i> Ait. var. <i>alpinum</i> .....	June 7	811	July 12	1,821
(621) <i>Delphinium triste</i> Fisch.....	June 1	723	July 1	1,176
(622) <i>Aconitum cammarum</i> L.....	July 19	1,444	Aug. 23	1,989
(623) <i>Aconitum japonicum</i> L.....	Sept. 17	2,292	.....	.....
(624) <i>Aconitum lycoctonum</i> L. var. <i>puberulum</i> .....	June 18	952	Aug. 5	1,684
(625) <i>Aconitum napellus</i> L.....	June 25	1,069	July 30	1,641
(626) <i>Botrophis actæoides</i> .....	July 1	1,141	.....	.....
(627) <i>Pæonia albiflora</i> Pallas. var. <i>rosea</i> .....	May 28	672	Aug. 3	1,678
(628) <i>Pæonia moutan</i> L. var. <i>papaveracea</i> .....	May 16	514	Aug. 7	1,759
(629) <i>Pæonia officinalis</i> Retz. var. <i>puberula</i> .....	May 18	548	Aug. 8	1,766
(630) <i>Pæonia tenuifolia</i> L.....	May 7	442	July 6	1,247
LXIII. <i>Berberidææ</i> [G. 5].				
(631) <i>Leontice vesicaria</i> Pall.....	Apr. 19	256	.....	.....
(632) <i>Epimedium alpinum</i> L.....	Apr. 26	341	.....	.....
(633) <i>Berberis aquifolium</i> Pursh. v. <i>repens</i> .....	Apr. 22	310	July 25	1,496
(634) <i>Berberis provincialis</i> Audib. Schrad. Lodd.....	May 11	472	Aug. 6	1,736

## Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
LXIV. <i>Papaveraceæ</i> [G. 8].				
		°Réaum.		°Réaum.
(635) <i>Chelidonium majus</i> L.....	May 5	403	June 5	785
(636) <i>Papaver orientale</i> L .....	May 25	645	June 28	1,149
(637) <i>Papaver rhœas</i> L (from self-sown seed).....	May 19	565	June 16	946
(638) <i>Papaver somniferum</i> L (from self-sown seed) .....	June 17	994	July 10	1,219
(639) <i>Glaucium luteum</i> Scop .....	June 1	704	July 21	1,461
(640) <i>Fumaria officinalis</i> L .....	Apr. 24	316	June 8	823
LXV. <i>Cruciferae</i> [G. 10].				
(641) <i>Barbarea vulgaris</i> R. Br.....	Apr. 28	342	June 30	1,144
(642) <i>Arabis alpina</i> L .....	Apr. 8	196	June 3	747
(643) <i>Berteroa incana</i> D. C.....	June 13	895	July 21	1,453
(644) <i>Alyssum saxatile</i> L.....	Apr. 19	283	June 8	802
(645) <i>Armoracia rusticana</i> L.....	May 15	512	June 27	1,103
(646) <i>Cochlearia officinalis</i> L .....	Apr. 5	214	May 31	703
(647) <i>Iberis sempervirens</i> L.....	Apr. 23	317	June 25	1,074
(648) <i>Hesperis matronalis</i> L .....	May 20	544	July 6	1,261
(649) <i>Sisymbrium austriacum</i> Jacq .....	May 6	896	June 22	1,012
(650) <i>Erysimum crepidifolium</i> Reichb .....	May 4	377	July 4	1,231
(651) <i>Isatis tinctoria</i> L.....	May 6	416	June 14	893
(652) <i>Brassica melanosinapis</i> Koch (sown May 2) .....	May 31	275	.....	.....
(653) <i>Raphanus sativus</i> L. (sown Apr. 28).....	June 12	703	Aug. 5	1,376
LXVI. <i>Resedaceæ</i> [G. 12].				
(654) <i>Reseda lutea</i> L.....	May 20	627	.....	.....
(655) <i>Reseda luteola</i> L.....	May 9	437	July 17	957
LXVII. <i>Nymphæaceæ</i> [G. 6].				
(656) <i>Nymphæa alba</i> L .....	May 25	649	.....	.....
(657) <i>Nymphæa lutea</i> Sm .....	May 26	646	July 28	2,046
LXVIII. <i>Cistaceæ</i> [G. 13].				
(658) <i>Helianthemum celandicum</i> Wahlenb.....	May 20	576	June 22	1,002
(659) <i>Helianthemum vulgare</i> Gärtner .....	May 23	595	....do....	1,025
LXIX. <i>Violariæ</i> [G. 14].				
(660) <i>Viola arenaria</i> D. C .....	Apr. 14	244	.....	.....
(661) <i>Viola hirta</i> L. <i>ambigua</i> .....	Apr. 6	174	.....	.....
(662) <i>Viola montana</i> L.....	Apr. 9	182	.....	.....
(663) <i>Viola odorata</i> L.....	Mar. 30	157	June 2	747
(664) <i>Viola pratensis</i> M. et K .....	Apr. 26	325	June 15	919
(665) <i>Viola tricolor</i> L.....	Apr. 9	234	June 12	907
LXX. <i>Caryophyllæ</i> [G. 15].				
(666) <i>Cerastium arvense</i> L.....	May 7	419	June 9	824
(667) <i>Dianthus carthusianorum</i> L. <i>medius</i> .....	June 4	769	July 14	1,346
(668) <i>Dianthus deltoides</i> L .....	May 28	657	June 25	1,064
(669) <i>Dianthus plumarius</i> L. var. <i>virens</i> .....	May 22	592	June 26	1,070
(670) <i>Gypsophila altissima</i> L .....	May 28	689	June 30	1,139
(671) <i>Gypsophila fastigata</i> L. <i>elatior</i> .....	June 13	890	July 20	1,454
(672) <i>Saponaria officinalis</i> L. <i>plena</i> .....	July 16	1,399	.....	.....
(673) <i>Silene inflata</i> Smith .....	June 4	759	June 29	1,141
(674) <i>Silene nutans</i> L. <i>albiflora</i> .....	May 17	526	June 12	873
(675) <i>Silene pseudotites</i> Bess .....	May 31	716	July 7	1,276
(676) <i>Silene saxifraga</i> L .....	June 1	733	June 25	1,036
(677) <i>Lychnis coronaria</i> Lam.....	June 27	1,165	.....	.....
(678) <i>Lychnis flos Jovis</i> Lam .....	June 13	882	.....	.....
(679) <i>Lychnis viscaria</i> L. <i>plena</i> .....	May 18	546	June 16	890

## Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
LXXI. <i>Phytolaccaceæ</i> [G. 88].				
(680) <i>Phytolacca decandra</i> L.....	July 12	1,325	Sept. 11	2,288
LXXII. <i>Malvaceæ</i> [G. 20].				
(681) <i>Lavatera thuringiaca</i> L.....	July 4	1,222	Aug. 2	1,668
(682) <i>Althæa cannabina</i> L.....	July 27	1,535	Aug. 23	1,991
(683) <i>Althæa ficifolia</i> Cav.....	July 5	1,229	Aug. 2	1,752
(684) <i>Althæa officinalis</i> L.....	July 14	1,365	Aug. 12	1,840
(685) <i>Althæa rosea</i> Cav.....	July 4	1,187	July 31	1,654
(686) <i>Malva rotundifolia</i> L.....	May 27	612	July 19	943
(687) <i>Malva silvestris</i> L.....	June 5	801	July 7	1,253
(688) <i>Hibiscus moscheutos</i> L.....	Aug. 23	1,943	.....	.....
(689) <i>Hibiscus syriacus</i> L.....	Aug. 11	1,803	.....	.....
LXXIII. <i>Tiliaceæ</i> [G. 21].				
(690) <i>Tilia argentea</i> L. fructu depressa.....	July 4	1,225	Sept. 9	2,138
(691) <i>Tilia grandifolia</i> Ehrh. latebracteata Host.....	June 11	871	July 29	1,607
(692) <i>Tilia parvifolia</i> Ehrh. ovatifolia, variegata.....	June 21	1,021	July 21	1,609
LXXIV. <i>Hypericinæ</i> [G. —].				
(693) <i>Hypericum perforatum</i> L.....	June 16	942	Aug. 23	1,988
LXXV. <i>Humiriaceæ</i> [G. —].				
(694) <i>Tamarix gallica</i> L. var. libanotica.....	June 3	740	.....	.....
LXXVI. <i>Acerinæ</i> [G. —; see G. 29].				
(695) <i>Acer campestre</i> var. <i>tauricum</i> .....	Apr. 30	365	Sept. 7	2,200
(696) <i>Acer eriocarpum</i> Michx ♂.....	Mar. 21	125	.....	.....
(697) <i>Acer monspessulanum</i> L.....	Apr. 2	292	Sept. 3	2,095
(698) <i>Acer obtusatum</i> Kitaib. var. <i>neapolitanum</i> .....	Apr. 10	232	Aug. 20	1,856
(699) <i>Acer platanoides</i> L.....	Apr. 14	246	Sept. 20	2,469
(700) <i>Acer pseudoplatanus</i> L. variegatum.....	May 1	373	Sept. 9	2,192
(701) <i>Acer sanguineum</i> Spach.....	Apr. 2	176	.....	.....
(702) <i>Acer saccharinum</i> L.....	(702)	(702)	.....	.....
(703) <i>Acer striatum</i> L.....	May 1	374	.....	.....
(704) <i>Acer tataricum</i> L.....	May 12	478	Aug. 13	1,827
(705) <i>Negundo fraxinifolium</i> Nutt ♂.....	Apr. 11	228	.....	.....
LXXVII. <i>Sapindaceæ</i> [G. 29].				
(706) <i>Kölreuteria paniculata</i> L.....	June 24	1,061	Aug. 27	2,062
(707) <i>Æsculus flava</i> Ait.....	May 11	460	.....	.....
(708) <i>Æsculus hippocastanum</i> L.....	May 5	409	Sept. 13	2,267
(709) <i>Æsculus macrostachys</i> Michx.....	July 10	1,300	Sept. 11	2,219
(710) <i>Æsculus pavia</i> L.....	May 9	448	.....	.....
LXXVIII. <i>Staphylaceæ</i> [G. —; see G. 29].				
(711) <i>Staphylea pinnata</i> L.....	May 7	428	.....	.....
LXXIX. <i>Celastrinæ</i> [G. 26].				
(712) <i>Euonymus europæus</i> L.....	May 23	601	.....	.....
(713) <i>Euonymus latifolius</i> L.....	May 11	466	Aug. 15	1,864
(714) <i>Celastrus scandens</i> L.....	May 24	634	Aug. 11	1,791

## Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
LXXX. <i>Rhamnaceæ</i> [G. 27].				
(715) <i>Paliurus aculeatus</i> Lam .....	June 7	832	.....	.....
(716) <i>Rhamnus cathartica</i> L.....	(716)	(716)	.....	.....
(717) <i>Rhamnus frangula</i> L .....	May 20	558	July 7	1,243
(718) <i>Ceanotus americanus</i> L.....	June 30	1,195	.....	.....
LXXXI. <i>Euphorbiaceæ</i> [G. 98].				
(719) <i>Euphorbia cyparissias</i> L .....	Apr. 10	226	June 4	773
(720) <i>Euphorbia esula</i> L.....	May 5	430	.....	.....
(721) <i>Euphorbia lathyris</i> L .....	.....	.....	July 27	1,541
(722) <i>Euphorbia pilosa</i> L. var. <i>tuberculata</i> .....	May 2	368	June 16	953
(723) <i>Mercurialis perennis</i> L.....	Apr. 26	208	.....	.....
(724) <i>Buxus sempervirens</i> L.....	Apr. 16	268	.....	.....
LXXXII. <i>Juglandaceæ</i> [G. 101].				
(725) <i>Juglans cinerea</i> L.....	May 5	418	.....	.....
(726) <i>Juglans nigra</i> L.....	May 15	503	.....	.....
(727) <i>Juglans regia</i> L. var. <i>maxima</i> .....	May 13	480	Sept. 12	2,268
(728) <i>Juglans regia</i> L. var. <i>serotina</i> .....	June 10	828	.....	.....
LXXXIII. <i>Anacardiaceæ</i> [G. 90].				
(729) <i>Rhus cotinus</i> L.....	May 22	593	July 6	1,270
(730) <i>Rhus typhina</i> L.....	June 12	875	.....	.....
LXXXIV. <i>Zanthoxyleæ</i> [G. —; see G. 24].				
(731) <i>Ptelea trifoliata</i> L.....	June 9	845	Aug. 21	1,979
(732) <i>Ailanthus glandulosa</i> Desf.....	June 17	956	Sept. 12	2,255
LXXXV. <i>Diosmeæ</i> [G. —].				
(733) <i>Dictamnus fraxinella</i> Pers.....	May 26	640	July 19	1,448
LXXXVI. <i>Rutaceæ</i> [G. 24].				
(734) <i>Ruta graveolens</i> L.....	June 4	765	Aug. 21	1,954
LXXXVII. <i>Zygophylleæ</i> [G. —].				
(735) <i>Zygophyllum fabago</i> L.....	July 4	1,221	.....	.....
LXXXVIII. <i>Geraniaceæ</i> [G. 23].				
(736) <i>Geranium pratense</i> L .....	June 8	845	July 10	1,289
(737) <i>Geranium pyrenaicum</i> .....	May 25	622	.....	.....
(738) <i>Geranium sanguineum</i> L.....	May 19	559	July 4	1,210
LXXXIX. <i>Linææ</i> [G. 22].				
(739) <i>Linum austriacum</i> L.....	May 5	427	June 28	1,134
(740) <i>Linum glandulosum</i> Mönch. var. <i>flavum</i> .....	June 8	831	July 28	1,619
(741) <i>Linum usitatissimum</i> L. (sown Apr. 29) .....	June 22	688	July 24	1,176
XC. <i>Oxalidææ</i> [G. —; see G. 23].				
(742) <i>Oxalis acetosella</i> L.....	Apr. 8	248	.....	.....
(743) <i>Oxalis stricta</i> L .....	May 25	602	.....	.....
XCI. <i>Philadelphææ</i> [G. —; see G. 35].				
(744) <i>Philadelphus coronarius</i> L.....	May 31	700	Aug. 16	1,892



*Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.*

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
XCII. <i>Enotheræ</i> [G. —; see G. 42].				
		°Réaum.		°Réaum.
(745) <i>Enothera biennis</i> L.....	June 15	918	Aug. 2	1,671
(746) <i>Enothera pumila</i> L.....	June 12	858	July 10	1,280
(747) <i>Epilobium angustifolium</i> L.....	June 29	1,113	.....	.....
(748) <i>Epilobium hirsutum</i> L.....	July 5	1,217	Aug. 8	1,766
XCIII. <i>Lythrarieæ</i> [G. 41].				
(749) <i>Lythrum salicaria</i> L.....	June 19	984	Aug. 3	1,685
(750) <i>Lythrum virgatum</i> L.....	July 16	1,344	.....	.....
XCIV. <i>Pomacææ</i> [G. —; see G. 33].				
(751) <i>Cydonia chinensis</i> Thuin.....	May 13	492	.....	.....
(752) <i>Cydonia japonica</i> Pers.....	Apr. 14	268	.....	.....
(753) <i>Cydonia vulgaris</i> Pers.....	May 13	481	Sept. 13	2,269
(754) <i>Pyrus americana</i> Spr.....	May 19	571	Sept. 17	1,413
(755) <i>Pyrus aria</i> Ehrh. var. <i>oblonga</i> .....	May 11	463	Aug. 25	1,934
(756) <i>Pyrus baccata</i> L.....	(756)	(756)	.....	.....
(757) <i>Pyrus chamæmespilus</i> Lindl.....	May 7	420	July 16	1,360
(758) <i>Pyrus communis</i> L. var. <i>sanguinea</i> .....	Apr. 28	336	.....	.....
(759) <i>Pyrus lanuginosa</i> D. C.....	May 5	410	July 6	1,248
(760) <i>Pyrus nivalis</i> L.....	May 2	395	.....	.....
(761) <i>Pyrus malus</i> L. var. <i>acerba</i> .....	May 20	535	.....	.....
(762) <i>Pyrus prunifolia</i> Willd. <i>xanthocarpa minor</i> .....	Apr. 26	343	July 27	1,538
(763) <i>Pyrus sorbus</i> Gärt. var. <i>pyriformis</i> .....	May 13	491	.....	.....
(764) <i>Pyrus torminalis</i> Ehrh.....	do	489	Aug. 7	1,758
(765) <i>Mespilus germanica</i> L.....	May 20	579	Sept. 26	2,418
(766) <i>Amelanchier canadensis</i> F. and A. Gr. <i>subcordata</i> .....	Apr. 18	335	.....	.....
(767) <i>Cotoneaster vulgaris</i> Lindl.....	Apr. 22	312	June 26	1,090
(768) <i>Cratægus monogyna</i> Jacq.....	May 11	464	Aug. 12	1,842
(769) <i>Cratægus oxyacantha</i> L. <i>splendens</i> , <i>roscæ</i> , <i>plena</i> .....	May 15	512	Aug. 19	1,933
(770) <i>Cratægus sanguinea</i> Pallas.....	May 10	475	July 27	1,603
(771) <i>Cratægus virginica</i> Michx.....	May 16	532	Aug. 12	1,840
XCV. <i>Rosacææ</i> [G. —].				
(772) <i>Rosa alba</i> L.....	June 9	855	.....	.....
(773) <i>Rosa alpina</i> L. ( <i>R. canina</i> L. var. <i>plena</i> ).....	May 19	547	July 24	1,500
(774) <i>Rosa canina</i> L.....	June 3	753	Aug. 20	1,947
(775) <i>Rosa centifolia</i> L.....	(775)	(775)	.....	.....
(776) <i>Rosa damascena</i> L.....	June 10	877	.....	.....
(777) <i>Rosa eglanteria</i> L.....	May 26	648	July 22	1,499
(778) <i>Rosa gallica</i> L.....	June 15	874	.....	.....
(779) <i>Rubus fruticosus</i> L. <i>plenus roseus</i> .....	June 27	1,103	.....	.....
(780) <i>Rubus idæus</i> L.....	May 20	562	June 26	1,080
(781) <i>Rubus odoratus</i> L.....	June 17	909	.....	.....
(782) <i>Fragaria collina</i> Ehrh.....	May 4	410	June 6	790
(783) <i>Fragaria vesca</i> L.....	Apr. 27	345	do	787
(784) <i>Potentilla alba</i> L.....	Apr. 8	218	.....	.....
(785) <i>Potentilla anserina</i> L.....	May 12	453	.....	.....
(786) <i>Potentilla argentea</i> L. <i>impolita</i> .....	May 19	580	.....	.....
(787) <i>Potentilla argentea</i> L.....	May 5	393	.....	.....
(788) <i>Potentilla atrosanguinea</i> Don.....	June 15	896	.....	.....
(789) <i>Potentilla aurea</i> L.....	Apr. 29	346	.....	.....
(790) <i>Potentilla chrysantha</i> Trevir. <i>minor</i> .....	Apr. 30	366	.....	.....

## Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
XCV. <i>Rosaceæ</i> [G. —]—Continued.				
		° Réaum.		° Réaum.
(791) <i>Potentilla fruticosa</i> L.....	May 15	525	.....	.....
(792) <i>Potentilla hirta</i> L.....	May 25	597	.....	.....
(793) <i>Potentilla pennsylvanica</i> L.....	June 18	950	.....	.....
(794) <i>Potentilla pulcherrima</i> Lehm. <i>minuta</i> .....	June 2	751	.....	.....
(795) <i>Potentilla reptans</i> L.....	....do....	746	.....	.....
(796) <i>Potentilla rupestris</i> L.....	May 9	458	.....	.....
(797) <i>Agrimonia eupatorium</i> L. <i>cafra</i> .....	June 22	1,025	Aug. 18	1,923
(798) <i>Agrimonia odorata</i> Mill .....	July 27	1,407	Sept. 20	2,414
(799) <i>Alchemilla montana</i> Willd .....	May 4	402	.....	.....
(800) <i>Sanguisorba officinalis</i> L. <i>auriculata</i> .....	(800)	(800)	.....	.....
(801) <i>Poterium sanguisorba</i> L .....	May 27	663	June 26	1,075
(802) <i>Waldsteinia geoides</i> Willd.....	Apr. 7	216	.....	.....
(803) <i>Geum coccineum</i> Sib .....	May 29	701	.....	.....
(804) <i>Geum rivale</i> L .....	May 9	386	June 20	998
(805) <i>Geum silvaticum</i> Desrouss.....	May 15	529	June 18	971
(806) <i>Geum urbanum</i> L.....	May 19	554	July 6	1,243
(807) <i>Coluria geoides</i> R. Br .....	Apr. 17	229	May 28	690
(808) <i>Kerria japonica</i> D. C.....	May 15	410	.....	.....
(809) <i>Spiræa acuminata</i> L.....	June 5	787	.....	.....
(810) <i>Spiræa chamaedryfolia</i> L. var. <i>oblongifolia</i> .....	May 4	389	June 20	983
(811) <i>Spiræa filipendula</i> L .....	June 4	762	July 14	1,325
(812) <i>Spiræa hypericifolia</i> D. C .....	May 9	425	June 13	927
(813) <i>Spiræa hypericifolia</i> D. C. var. <i>Plukenetii</i> .....	Apr. 20	288	.....	.....
(814) <i>Spiræa opulifolia</i> L.....	May 26	641	July 9	1,295
(815) <i>Spiræa sorbifolia</i> L .....	June 16	980	Aug. 8	1,741
(816) <i>Spiræa ulmaria</i> L. var. <i>variegata</i> .....	June 21	1,022	....do....	1,734
(817) <i>Spiræa ulmifolia</i> Scop.....	May 17	510	July 18	970
XCVI. <i>Amygdalææ</i> [G. —].				
(818) <i>Amygdalus communis</i> L. <i>variegata</i> .....	Apr. 13	247	Sept. 8	2,228
(819) <i>Amygdalus divaricata</i> .....	Apr. 2	169	.....	.....
(820) <i>Amygdalus nana</i> L.....	Apr. 20	293	.....	.....
(821) <i>Amygdalus persica</i> L. <i>plena rosea</i> .....	Apr. 24	306	.....	.....
(822) <i>Prunus acida</i> Ehrh.....	Apr. 23	311	June 22	1,023
(823) <i>Prunus americana</i> .....	Apr. 19	280	.....	.....
(824) <i>Prunus avium</i> L .....	....do....	291	.....	.....
(825) <i>Prunus cerasifera</i> Ehrh.....	....do....	290	July 13	1,340
(826) <i>Prunus domestica</i> L. var. <i>Claudiana semiplena</i> .....	May 4	374	.....	.....
(827) <i>Prunus mahaleb</i> L.....	Apr. 29	358	June 28	1,123
(828) <i>Prunus padus</i> L.....	Apr. 28	349	June 23	1,054
(829) <i>Prunus sibirica</i> L .....	Apr. 8	233	July 11	1,330
(830) <i>Prunus serotina</i> Ehrh.....	May 24	623	Aug. 10	1,763
(831) <i>Prunus spinosa</i> L.....	Apr. 24	321	July 22	1,478
(832) <i>Prunus virginiana</i> L.....	May 4	388	June 22	1,147
XCVII. <i>Papilionacææ</i> [G. —; see G. 32].				
(833) <i>Lupinus polyphyllus</i> Dougl.....	May 21	580	July 2	1,167
(834) <i>Ononis natrix</i> L..... (834)	June 18	965	{ July 25	1,525
			{ Aug. 9	1,810
(835) <i>Ononis spinosa</i> L.....	June 25	1,069	Aug. 5	1,710
(836) <i>Ulex europæus</i> L.....	May 17	540	July 6	1,216

*Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.*

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
XCVII. <i>Papilionaceæ</i> [ <i>G.</i> —; <i>see G. 32</i> ]—Continued.		°Réaum.		°Réaum.
(837) <i>Spartium junceum</i> L.....	June 7	802	Aug. 13	1,842
(838) <i>Genista tinctoria</i> L. <i>virgata</i> .....	July 18	1,018	.....	.....
(839) <i>Cytisus alpinus</i> Mill. <i>macrostachys</i> .....	May 28	667	July 22	1,502
(840) <i>Cytisus biflorens</i> Host.....	May 3	389	June 24	1,070
(841) <i>Cytisus elongatus</i> M. and K.....,	Apr. 29	362	June 25	1,087
(842) <i>Cytisus laburnum</i> L.....	May 14	497	July 29	1,598
(843) <i>Cytisus nigricans</i> L.....	June 22	994	Aug. 15	1,831
(844) <i>Anthyllis montana</i> L.....	May 17	555	July 19	1,479
(845) <i>Medicago sativa</i> L.....	June 8	827	Aug. 5	1,719
(846) <i>Melilotus officinalis</i> L.....	June 11	855	Aug. 7	1,661
(847) <i>Trifolium alpestre</i> L.....	June 4	766	July 14	1,889
(848) <i>Trifolium montanum</i> L.....	May 16	548	June 24	1,100
(849) <i>Trifolium pratense</i> L.....	May 30	687	June 25	1,075
(850) <i>Trifolium repens</i> L.....	June 1	670	.....	.....
(851) <i>Dorycnium herbaceum</i> Willd.....	June 16	957	July 27	1,607
(852) <i>Tetragonolobus siliquosus</i> Roth.....	May 21	593	July 2	1,153
(853) <i>Amorpha fruticosa</i> L.....	June 7	805	Sept. 16	2,305
(854) <i>Psoralea acaulis</i> Steven.....	June 15	900	July 25	1,523
(855) <i>Glycyrrhiza glabra</i> L.....	June 26	1,098	Aug. 13	1,363
(856) <i>Galega officinalis</i> L.....	June 16	951	July 30	1,644
(857) <i>Robinia hispida</i> L.....	May 21	588	.....	.....
(858) <i>Robinia pseudoacacia</i> L. var. <i>inermis</i> .....	May 30	683	.....	.....
(859) <i>Robinia viscosa</i> L.....	May 31	718	Aug. 27	2,064
(860) <i>Caragana arborescens</i> Lam.....	May 3	391	July 14	1,326
(861) <i>Caragana frutescens</i> L. <i>silvatica</i> .....	May 7	430	June 26	1,027
(862) <i>Colutea arborescens</i> .....	May 27	649	July 14	1,361
(863) <i>Astragalus cicer</i> L.....	June 6	808	July 12	1,339
(864) <i>Astragalus galegiformis</i> Sibth.....	May 30	697	July 8	1,256
(865) <i>Astragalus illyricus</i> Bernh.....	May 4	403	.....	.....
(866) <i>Astragalus maximus</i> Willd.....	June 6	813	July 20	1,478
(867) <i>Astragalus onobrychis</i> L. <i>microphyllus</i> .....	June 5	787	July 28	1,613
(868) <i>Pisum sativum</i> Poir (sown May 2).....	July 2	782	July 30	1,256
(869) <i>Ervum lens</i> L. (sown May 2).....	June 25	688	July 26	1,169
(870) <i>Lathyrus latifolius</i> L.....	June 12	893	Aug. 2	1,674
(871) <i>Lathyrus silvestris</i> L. var. <i>ensifolius</i> .....	June 8	814	.....	.....
(872) <i>Orobus albus</i> L. <i>rubescens</i> .....	May 3	407	June 22	1,021
(873) <i>Orobus niger</i> L.....	May 27	669	July 21	1,481
(874) <i>Orobus roseus</i> Ledeb.....	May 25	646	.....	.....
(875) <i>Orobus vernus</i> L. var. <i>flaccidus</i> .....	Apr. 29	291	June 7	824
(876) <i>Orobus versicolor</i> Gmel.....	May 9	444	.....	.....
(877) <i>Coronilla emerus</i> L.....	May 10	454	July 12	1,364
(878) <i>Coronilla minima</i> L.....	May 5	443	July 7	1,269
(879) <i>Coronilla montana</i> L.....	May 27	664	Aug. 1	1,656
(880) <i>Coronilla varia</i> L..... (880)	June 12	869	July 26	1,552
			Aug. 15	1,839
(881) <i>Onobrychis satia</i> L.....	May 22	634	June 29	1,138
(882) <i>Phaseolus vulgaris</i> Savi. (sown May 2).....	July 2	778	Aug. 8	1,387
(883) <i>Cladrastis tinctoria</i> Raf.....	June 4	765	.....	.....
(884) <i>Styphnolobium japonicum</i> Schott.....	Aug. 4	1,672	.....	.....

*Thermal constants for the blossoming and ripening of 889 plants, etc.—Continued.*

Designation of plant: order, genus, and species.	Flowering.		Ripening.	
	Date.	Con- stant.	Date.	Con- stant.
XCVII. <i>Papilionaceæ</i> [ <i>G.</i> —; <i>see G. 32</i> —Continued.		°Réaum.		°Réaum.
(885) <i>Cercis canadensis</i> L.....	May 8	449	.....	.....
(886) <i>Cercis siliquastrum</i> L.....	May 16	511	Oct. 5	2,430
(887) <i>Gleditschia triacanthos</i> L. <i>inermis</i> .....	June 5	756	Sept. 20	2,332
(888) <i>Gymnocladus canadensis</i> Lam.....	June 4	763	.....	.....
(889) <i>Cassia marylandica</i> L.....	July —	1,631	.....	.....

54. Very rarely blossoms.  
57. The fruit ripens during the following season.  
168 and 175. Did not bloom during the ten years.  
179 and 189. Tree too young to blossom.  
203. The concealed blossoms can not be accurately observed.  
270 and 271. The dates of blossoming are too variable to allow of determining a thermal constant.  
304. These figures obtain for moist years, but for dry years we have September 9 and 2237, respectively.  
308. Blossomed only once during these ten years.  
518. The blossoming of the tree is not easy to observe.  
577. The tree died in 1855.  
580 and 581. Too young to blossom.  
702 and 775. Did not blossom.  
716. Blossomed only once and died in 1857.  
756. Did not blossom and died in 1856.  
800. Dates are too variable to allow determining a thermal constant.  
834 and 880. The dates when the hull hardens and colors and when it springs open, allowing the fruit to fall, are both given.

## LINSER.

The most elaborate and, I believe, the most important investigation into the relation between plant life and climate is that published by Karl Linsser in a first memoir (St. Petersburg, 1867) and in a second memoir of 1869. My personal association with him during 1865 and 1866 greatly stimulated my own early interest in the subject. The conclusions arrived at by Linsser are based upon the study of all available European observations. His knowledge of physics and skill in numerical computations as the chief of the computing division of the Imperial Astronomical Observatory at Poulkova has given his results a precision based on the well-established principles of probabilities and a clearness of interpretation that specially commend them to the physiological botanist. Linsser states that the principal hypotheses that had up to his time been framed as to the form of the connection between the phenomena of temperature and of phenology are the following three:

- (1) That for the same plant the same stage of vegetation occurs from year to year on the attainment of the same mean daily temperature.

(2) That the same stage of vegetation is attained when in the course of any year the sum total of the mean daily temperatures above freezing attains the same value.

(3) That the same stage of vegetation is attained when in the course of any year the sum of the squares of these positive temperatures attains a certain constant value.

The first of these hypotheses has, he states, long since been given up as of insufficient accuracy not only for any given station, but still more when we consider the temperatures belonging to a given stage of vegetation of the same plant in localities that differ much in latitude or longitude.

The third hypothesis is that which was favored by Quetelet, and the second is that which had for a hundred years been generally adopted by botanists. Both of these two latter hypotheses were most thoroughly investigated by Erman in his memoir, published in 1845 and 1849.<sup>a</sup>

Erman demonstrates that both these hypotheses are unsatisfactory, but Linsser proposes to reinvestigate the question on the basis of a much larger collection of material, both phenological and meteorological.

The first step in Linsser's investigation consists in finding a method of computing the sums of the temperatures or the sums of the squares of the temperatures above freezing when the average temperature of any day of the year is expressed by the so-called sine and cosine formula of Bessel. He computes the coefficients of Bessel's formula, and therefore knows the equations that express the mean daily temperature for any day in the year and for each of his stations of observations.<sup>b</sup>

The summation of the squares of the mean daily temperatures was computed by Linsser by the method known as mechanical quadratures. The following table illustrates his results for seven groups of

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<sup>a</sup> I very much regret that I have not been able to examine these memoirs, which are published in the *Archiv für Wissenschaftliche Kenntnisse Russland*, Vols. IV and VIII.—C. A.

<sup>b</sup> A similar computation had been made by Erman, but for the benefit of those who may in the future have to go through similar labors I would suggest that it is not more laborious and is certainly more perspicuous to compute the actual daily temperature for every fourth day of the year, beginning with January 0, and in the adjoining column make up the continuous summations. The difference between the sums for any two dates is then the total mean daily temperature to which the plant has been subjected.—C. A.

plants that were observed at Brussels and at Poulkova, which is 12 miles south of St. Petersburg:

Group of plants.	Date of blossoming.		Sums for Brussels.		Sums for Poulkova.	
	Brussels.	Poulkova.	Temperature.	Squares of temperature.	Temperature.	Squares of temperature.
	Days.	Days.	° C.	° C.	° C.	° C.
1.....	85.4	137.4	247	1,022	180	1,145
2.....	98.9	149.0	347	1,751	300	2,304
3.....	119.9	161.4	550	3,730	458	4,411
4.....	138.0	169.5	773	6,497	575	6,100
5.....	160.4	184.2	1,102	11,506	807	9,776
6.....	181.6	190.5	1,471	17,764	912	11,527
7.....	222.0	223.0	2,219	31,615	1,460	20,700

In taking these sums, which all relate to positive temperatures on the centigrade thermometer only, Linsser begins with April 8 at Poulkova, because on that date the gradually rising daily temperatures pass through the freezing point. It would have made no difference if he had begun with January 1, or December 1, or with the date of lowest mean temperature, which would be about the middle of January. On the other hand, for Brussels his sums begin with January 15, which is the date at which the lowest mean daily temperature occurs, which temperature is about +2.5° C., so that if he had begun with January 1 there would have been a constant slight addition to all the numbers in that column. The dates of blossoming are given in days counting consecutively from the 1st of January, and may be converted into the days of the month or vice versa by the following table:

Date.	Day of the year.		Date.	Day of the year.	
	Ordinary.	Leap.		Ordinary.	Leap.
January 1.....	1	1	August 1.....	213	214
February 1.....	32	32	September 1.....	244	245
March 1.....	60	61	October 1.....	274	275
April 1.....	91	92	November 1.....	305	306
May 1.....	121	122	December 1.....	335	336
June 1.....	152	153	January 1.....	306	307
July 1.....	182	183			

If we take the difference between the sums of the temperatures for the first and seventh groups of plants in the preceding table we obtain for Brussels 1,972° C., and for Poulkova 1,280° C., or a difference of about 700° C., which corresponds to about forty days at Poulkova, so that we must immediately conclude that the same stages of develop-

ment are attained by means of very different sum totals of temperatures at Poulkova and Brussels.

But possibly we should have taken the initial point of vegetation at some other temperature than  $0^{\circ}$  C. In order to test this point Linsser performs the computations of the sums of temperatures above  $1^{\circ}$ ,  $2^{\circ}$ ,  $3^{\circ}$ ,  $4^{\circ}$ ,  $5^{\circ}$ , and  $6^{\circ}$  C., respectively. His result for  $6^{\circ}$  C. is as follows:

Group.	Brussels.	Poulkova.	Group.	Brussels.	Poulkova.
	$^{\circ}$ C.	$^{\circ}$ C.		$^{\circ}$ C.	$^{\circ}$ C.
1.....	1	21	5.....	412	368
2.....	20	72	6.....	995	435
3.....	97	155	7.....	1,154	788
4.....	212	224			

None of these successive hypotheses as to the initial temperature for vegetation gives a uniform constant any more than does the original hypothesis of  $0^{\circ}$  C.

A similar study of the sums of the squares demonstrates a similar result, so that in general at different places the same phase of development of vegetation requires different mean daily temperatures, different sums of temperatures, and different sums of the squares of temperatures, and there is no zero point that can be adopted that will make these sums equal.

Linsser then shows that, notwithstanding this result, there still is a thermal law concealed in the above figures. For evidently the sums for Brussels and Poulkova go on steadily increasing through the whole period of vegetation, and at any stage the numbers are very nearly in the same proportion, and that proportion is very nearly the same as the proportion between the sum total for the year at the two places. These annual sums total are for Brussels 3,687, and for St. Petersburg 2,253. If now the numbers in the fourth and sixth columns of the table on page 213 be divided by these annual sums, respectively, we obtain the following:

*Ratio of the individual sums to the total annual sums of temperature above  $0^{\circ}$  C.*

Group of plants.	Brussels.	Poulkova.	Group of plants.	Brussels.	Poulkova.
1.....	0.07	0.08	5.....	0.30	0.36
2.....	.09	.13	6.....	.40	.40
3.....	.15	.20	7.....	.60	.65
4.....	.21	.26			

The agreement of these numbers is quite close enough to justify the conclusion that in two different localities the sums of positive daily temperatures for the same phase of vegetation is proportional to the



annual sum total of all positive temperatures for the respective localities. The discrepancies between the above figures also show that a systematic influence is at work to slightly increase the ratio for the northern stations, since the ratios for Poulkova are appreciably larger than those for Brussels. This influence, as Linsser suggests, is probably to be found in the fact that a larger proportion of heat is consumed at the northern stations in melting the snow without changing the temperature, which heat is therefore lost to the growth of plants.

The law thus discovered by Linsser is tested by him for each of the 15 phenological stations studied in his first memoir, and not only does the ratio appear the same for each phase, but the slight increase as the latitudes increase is also confirmed, or, in other words, the ratio increases slightly as the annual sum total of positive temperatures diminishes, the increase being nothing for the first group of plants that blossom early in the spring and about 0.1 for the seventh group of plants that blossom in midsummer per diminution of  $2,000^{\circ}$  C. in the annual sums.

Linsser also states this law in the following form, in which it has a more popular expression:

Every individual plant possesses the ability to regulate its vital activity as demanded by the total heat available in its dwelling place and according to the habit inherited from its ancestors, so that individuals of the same species living in different places arrive at the same phase of development by utilizing the same proportions of the total heat to which they are accustomed. The vegetable world, so far as we consider its vital phenomena, is indifferent to temperatures below the freezing point.

The preceding principle has been deduced primarily from the study of one phase, viz, the blossoming; but a study of the figures of the other phases gives a similar result, so that the method by which heat exercises its influence on plants is the same for all stages of development.

The phase recorded as "the falling of the leaves," which indicates the approach of the winter sleep of perennial plants, is the only one that to a high degree depends upon the actual temperature at that date.

Apparently the statement, frequently assumed as a general law, that the dates of leafing and of the falling of the leaf at the same place have the same temperatures is only approximately true for a single plant and a special locality, as, for instance, France and central Europe, and does not hold good for the same plant for northern or southern Europe.

Linsser's law has a most important application to the natural dissemination of seeds and the acclimatization of plants. When we, at a given place, from year to year, see the same cycle of vegetation recur without changing the behavior of the plant with reference to the annual sum total of heat, we must conclude that the ability to develop itself in proportion to the total heat is transmitted from each

mother plant down to the seed produced by it. Therefore in every kernel of seed there is concealed the whole relation between the development of the plant and the total heat of the locality where it was produced. Two seeds of the same species, one of which comes from a mother plant that has lived under the influence of an annual total heat of  $M$ , but the other of which comes from another mother plant that has lived under a total annual heat of  $N$ , possess powers of development, or a sensitiveness to equal temperature influences, that are inversely proportional to the sums  $M$  and  $N$ ; or, in other words, the rate of development is equal to the sum of the effective temperatures divided by the normal values of the total annual sums for the mother plant.

Applying this law to seeds that are artificially transported from their homes to other places having different climates as to temperature we are enabled to predict approximately what their behavior will be. Thus Von Baer observed that cress seeds that had been raised in St. Petersburg (lat.  $60^\circ$ ) and transported to Matotschkin-Schar (lat.  $73^\circ$ ) developed in July at only one-third the rate that they did in St. Petersburg in the month of May. Now the annual sum of positive temperatures for St. Petersburg is  $2,253^\circ$  C., and the average temperature of the month of May in St. Petersburg is  $11.2^\circ$ , while that of the month of July at Matotschkin-Schar is  $4.4^\circ$ . Therefore the rates of development per day of the same seed at these two places will be in the ratio of 11.2 to 4.4, or 2.6 to 1. Again, for cress seeds raised at Matotschkin-Schar, where the annual total heat is  $330^\circ$  C., the rate of development will in general be  $\frac{2253}{330}$ , or 6.8 times more rapid than the development of seeds brought from St. Petersburg. Vice versa, seeds carried from Matotschkin-Schar to St. Petersburg the rate of development will be 6.8 times more rapid than for those that are native to the latter climate.

Linsser was thus able to enunciate the first step in the rational explanation of a phenomenon with which agriculturists had long been familiar—viz, that the seeds raised in northern zones retain the power of rapid development, so that when sown in southern regions they grow more rapidly and ripen earlier and give a richer harvest than those that are sown in their native warm locality. Similarly, seeds of mountain plants, when carried by rivers into the warmer plains of the lowlands, develop plants whose blossoms antedate the spring blossoms of the plants native to the lowlands.<sup>a</sup> We may thus accept the general statement that plants or seeds transported to colder countries reach a given stage of vegetation later than the

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<sup>a</sup>A beautiful illustration of this law is found in the abnormal early flowering of seeds brought from the cold uplands and lodging on High Island, on the Potomac, about 5 miles above Washington, D. C.

native plants, but when transported to warmer regions they blossom and ripen earlier. Thus in 1859 Schuebeler sowed 6-rowed barley that had been raised in Alten (lat. 70° N.), where it required only nine weeks to ripen, in Christiania (lat. 60° N.), where it ripened in eight weeks. In the same year some of the same barley was carried from Breslau, where it required nine and a half weeks, to Christiania, where it ripened in twelve to fourteen weeks. Linsser arranged these experiences as shown in the following table, in which he assumes that both at Alten and at Christiania the barley is sown when the mean daily temperature is about 8° C.

Barley raised at—	Date of sowing.	Date of ripening.	Interval.	Sums of temperature.
			Weeks.	°C.
Alten and sown at Alten .....	June 14	Aug. 16	9	700
Alten and sown at Christiania .....	May 5	June 29	8	-----
Christiana and sown at Christiania .....	do	Aug. 1-9	13	1,400

The annual sum totals of heat are 1,300 in Alten and 2,600 in Christiania. Therefore we see that the heat required by seed acclimatized at Alten (700) is to that required by seed acclimatized at Christiania (1,400) in the same ratio as the annual sum totals.

It can also be shown that barley acclimatized at Christiania and transported directly to Alten can not ripen in the latter place, since the 1,400° C. required by it at Christiania are not received at Alten. It is only by gradual progressive acclimatization at numerous intermediate places that the plant has been enabled to adapt itself to successively smaller sum totals of heat. In continuation of this process the barley that is now accustomed to ripen at Alten can be used to pioneer the further northward progress of its species. The attempt to transport barley from Denmark to Iceland has thus far failed, but doubtless barley from Alten would succeed. Barley cultivated in the Caucasus at an elevation of 7,000 feet and transported to St. Petersburg should, according to Linsser's computation, experience an acceleration, so far as climate is concerned, as though it were coming to a warmer climate, but this acceleration may be more than counterbalanced by the differences in the nature of the two species of plants, as it is well known that the Turkish oats (*Avena orientalis*) require more time to ripen than the ordinary oats of northern Europe; the variations in times required by different kinds of oats, barley, and wheat, and even winter rye, are oftentimes larger than the variations due to differences of climate. But such variations, as observed in plants that are only partially acclimatized, will disappear after a few generations if the plant has the power of adapting its internal organ-

ization to a new climate. The geographical limits of any species, in latitude, so far as these limits depend upon temperature alone, are those points at which a certain sum of positive temperatures can be attained between the first and the last killing frost. The northern and southern boundary lines of such a limiting area are the curves corresponding to two very different sums total of positive temperatures, the northern limit having a smaller sum and the southern limit a larger, beyond either of which the plant is unable to modify its internal organization so as to properly utilize the respective prevailing small or large quantity of heat.

Linsser notes that different plants, especially those that blossom early in the year, show a strong tendency in certain years to blossom a second time, and he finds that when the excess of the total heat in a favorable year exceeds the normal annual total by a quantity equal to that ordinarily required for the first blossom (and this can easily happen on account of the small sum required for the early spring blossom) then the plant produces a second blossom.<sup>a</sup>

In regard to the effect of daylight as such, Linsser says the opinion has been expressed that possibly the duration of the daylight, which, during the growing period, increases as we go northward, must compensate for the diminishing sum total of heat; but his figures show nothing of this influence, since the discrepancies or departures between his observed and computed figures have altogether the character of accidental errors. In fact, his law of the constant quotient or percentage of heat implies that the plant does not need any compensation as the heat is diminished, but directly adapts its cycle of operations to the diminished sum and transmits this power to all further generations. In addition to this, however, since the importance of light to the plant is proven, it is necessary to remember that with the increasing duration of the day as we go northward there is a steady diminution in the intensity of the daylight because

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<sup>a</sup> Ought we not to infer from this that after a perennial plant has received sufficient heat to blossom and eventually to ripen its fruit it then at once begins to repeat this cycle of processes, and is ordinarily only delayed by the cold of winter? If this is true, it must be considered that with the warm weather of spring the plant takes up these vital processes at the point where they were left in the autumn. Therefore, in such cases, our sums total of temperature, moisture, etc., should all begin to be counted with the ripening of the fruit, or the fall of the leaf, and not merely with the opening of vegetation in the spring.—C. A.

the sun's altitude diminishes. This Linsser shows in the following table.<sup>a</sup>

Date.	Maximum duration of sunshine.		Altitude of sun at noon.		Relative quantity of heat received by the ground in 1 day under an atmosphere whose transparency is 0.70.			
	Venice (lat. 45.4° N.).	St. Pe- tersburg (lat. 60° N.).	Venice (lat. 45.4° N.).	St. Pe- tersburg (lat. 60° N.).	Lat. 40° N.	Lat. 50° N.	Lat. 60° N.	Lat. 70° N.
	Hours.	Hours.	Degrees.	Degrees.				
January 16 .....	9.0	6.8	23.7	9.0	150	70	15	0
February 15 .....	10.3	9.2	31.5	16.9	210	155	65	14
March 16 .....	11.9	11.8	42.8	28.2	400	295	190	95
April 15 .....	13.5	14.5	54.3	39.7	520	450	360	255
May 16 .....	14.8	17.2	63.6	49.1	615	570	505	425
June 15 .....	15.6	18.8	67.8	53.4	650	625	570	505
July 16 .....	15.3	18.1	66.0	51.5	630	585	525	450
August 16 .....	14.1	15.6	58.4	43.9	550	480	395	295
September 15 .....	12.6	13.0	47.7	33.2	430	335	230	125
October 16 .....	10.9	10.2	35.8	21.2	280	185	90	25
November 15 .....	9.5	7.6	26.2	11.6	180	85	20	0
December 16 .....	8.7	6.0	21.3	6.7	135	50	2	0

In reference to the first part of this table Linsser remarks that the intensity of the light of the sun varies as the sine of the angular altitude of the sun, so that from the maximum altitude on any day we get an approximate idea of the influence of sunshine; and we see also that the farther north we go the longer duration of the sunshine is partly counterbalanced by the diminishing intensity of its influence.<sup>b</sup>

Linsser remarks that the theory of compensation between duration of the day and intensity of sunshine may also be tested by considering the effect of ascending a mountain, where there is no increase of duration but a great increase in the intensity, of sunshine. If the rapid development of the plants on the mountains is due to the increase in the intensity of the light, then how can the diminution of intensity in northern regions bring about the rapid development that is demonstrated in the experiments of Von Baer and Schuebeler and Ruprecht which are quoted and analyzed in the following paragraphs?

<sup>a</sup>To which I have added three columns of relative intensity of the total heat received in twenty-four hours on each date, as interpolated from Angot's tables, for a coefficient of transparency equal to 0.70.—C. A.

<sup>b</sup>The exact figures that give the relative sum total of the direct sunshine and the diffuse daylight for various latitudes and solar altitudes for clear and cloudless days have been published by Marie Davy, Angot, Wiener, and others. The figures that I have given in the last part of the above tables from Angot show still more clearly to what extent the effect of sunshine diminishes as we approach the pole, but how surprisingly powerful are the consecutive twenty-four hours of sunshine on June 15 within the Arctic Circle.—C. A.

In his second memoir Linsser (1869) begins by showing that many well-recognized facts have been found which harmonize with the conclusions at which he had previously arrived. Thus, in the first and second halves of the eighteenth century the northern limit of the cultivation of grain had not passed beyond latitude  $60^{\circ} 30' N.$ , and many unsuccessful attempts had been made to ripen the grains in more northern regions; but in 1829 Erman found a small successful beginning going on at Yakutsk, and since then it has spread in all directions and has extended to barley, oats, rye, and wheat. Similarly in Lapland the cultivation of grain succeeded only for a long time in the southern regions, but now it extends to the north and even among the mountains. In Lapland this cultivation succeeded only when the seed was brought from near by, not from a distance, and Von Baer says that it was commonly said that the grain had acclimatized itself, or, as he expresses it, "It seems to me that gradually a quick-ripening variety or 'sport' has developed that is not injured by the early frosts of summer nights."

F. C. Schübeler (1862) in his memoir on the cultivated plants of Norway states that in 1852 the seed of yellow maize brought to Norway from Hohenheim, near Stuttgart, was sown on the 26th of May and reaped one hundred and twenty days later, but after continued annual cultivations, in which every harvest came a little earlier than its predecessor, Schübeler, in 1857, sowed the seed on May 25 and harvested it in ninety days, while the seed of the same variety brought fresh from Breslau and sowed on the same date ripened only after one hundred and twenty-two days. Even Kalm had remarked that maize when transported from a southern to a northern latitude gradually overcomes the difficulty of ripening and eventually gives a nearly constant variety of grain.

Morren, in the *Belgique Horticole* (1859-60), says the principal problem to be resolved in Norway in the amelioration of its agriculture is the introduction of new varieties and the development of precocity. This precocity increases year by year, as if the plant could not all of a sudden obey the new climatic influences under which it had been brought. Plants cultivated many years in succession under a northern climate when transported to a southern climate preserve something of their former rate of development and are more precocious than plants of the same species that have remained in their first situation. Just as wheat carried from Germany northward into the Baltic Provinces of Russia fails to ripen its grain, so grain carried from the valleys up to the highlands in Switzerland fails to ripen.

Bastian quotes an old English author who says that in the acclimatization of plants the graduation of the process is the principal necessity, and that a sudden acclimatization in a new home is impossible, so that a plant gradually learns to live in a climate in which



its mother plant was sickly and its grandmother would have died at once. It was in recognition of this view that in the eighteenth century the botanical garden at Teneriffe was established (the so-called acclimatization garden at Durasno and the Colegan Garden at Ortava, at an altitude of 1,040 feet) in order to furnish a temporary resting place for tropical plants that they might accustom themselves to a cooler climate preparatory to their cultivation in southern Europe. According to Döllén, the same principle is applied in the acclimatization garden at Algiers to tropical African plants before their transportation into southern France.

As the guiding thought of his second memoir, Linsser now remarks that we must divide the vegetable phenomena of the world into two divisions, viz. those in which temperature controls the annually recurring cycle of phases, as is the case in the Temperate Zone, and those in which moisture controls, as in the Tropical Zone. Thus, on the grassy plains of South America, where the year is divided into a dry and a wet season, the entire course of vegetation depends upon the latter; the hottest and driest season exerts upon the vegetable life an influence like that of the northern winter, bringing, namely, rest and even death. Such a contrast is even found at Madeira, where, according to Heer, the weeds of northern Europe begin to vegetate in the fall after the dry summer months of trade winds and when the first rains fall, whereas in the hottest summer time all these weeds slumber or die, as with us in winter. In the steppes of Orenburg, Russia, when the sun melts the snow in April, it starts the first sprouts and the blossoms, and by the beginning of May the vegetation of the steppes has attained its highest brilliancy, being distinguished by the great number of many-colored tulips, as has been so often described by travelers; but this beauty passes by with remarkable rapidity, and when in June the dry, hot summer of the steppes begins, all the verdure is dry and dead, and in place of the blossoms there are seen only the dry, empty hulls; so that the whole life of the plants on the steppes is condensed into the short space of eight weeks.

We thus see that for large portions of the earth the heat as such ceases to be the principal regulator of plant life, and moisture becomes the controlling influence.

It is evident that the life of plants depends upon both temperature and moisture. In situations where there is always sufficient moisture the influence that decides whether or not a plant shall develop is the heat; but in regions where there is always sufficient heat that deciding influence is moisture. Therefore Linsser proposes in his second memoir to first state the influence of heat on vegetable phenomena more precisely than he had previously done, and then to develop the influence of moisture.



Linsser's second study is based upon a much larger mass of phenological observations than that previously used by him, and, in fact, more than has ever been used by any other investigator of this subject. The accompanying table gives for each of his stations the initial and final dates when the normal mean daily temperature is  $0^{\circ}\text{C.}$ , or the date when the minimum of the year occurs if that minimum is above  $0^{\circ}\text{C.}$ ; these are the limiting dates between which the summation of temperature is made according to Linsser's method. The sums total of positive temperatures for the whole year are given in the third column in centigrade degrees.

Station.	Initial date.	Final date.	Annual sums of positive temperatures.	Linsser's zones.
			$^{\circ}\text{C.}$	
Possan.....	Jan. 15	Dec. 31	5,226	A
Parma.....	Jan. 17	do	4,797	B
Venice.....	Jan. 11	do	4,669	A
Dijon.....	Jan. 5	do	4,251	A
Heidelberg.....	Jan. 14	do	8,933	A
Paris.....	Jan. 13	do	3,929	A
Namur.....	do	do	3,865	A
Ghent.....	Jan. 12	do	3,815	A
Kischineff.....	Mar. 2	Dec. 8	3,799	B
Vienna.....	Feb. 8	Dec. 18	3,757	B
Ostend.....	Jan. 14	Dec. 31	3,737	A
Brussels.....	Jan. 16	do	3,687	A
Prague.....	Feb. 16	Dec. 16	3,582	B
Swaffham.....	Jan. 20	Dec. 31	3,520	A
Brunswick.....	Feb. 8	do	3,433	A
Sarepta.....	Mar. 27	Nov. 12	3,271	B
Stavelot.....	Jan. 20	Dec. 31	3,151	A
Munich.....	Feb. 14	Dec. 16	3,125	A
Tubingen.....	Feb. 9	Dec. 1	3,125	A
Stettin.....	Feb. 18	Dec. 18	3,115	A
Kief.....	Mar. 16	Nov. 21	3,035	B
Kreuzburg.....	Feb. 28	Dec. 16	3,018	A
Gorlitz.....	Feb. 19	Dec. 6	2,975	A
Breslau.....	Mar. 2	do	2,953	B
Orel.....	Apr. 1	Nov. 13	2,807	A
Moscow.....	Apr. 4	Nov. 4	2,631	A
Riga.....	Mar. 26	Nov. 22	2,574	A
Christiania.....	do	Nov. 11	2,389	A
Abo.....	Apr. 3	Nov. 13	2,303	A
St. Petersburg.....	Apr. 8	Nov. 9	2,253	A
Carlo.....	Apr. 19	Oct. 30	1,898	A

A plant has access to water by two methods—through its roots it absorbs the water in the soil, whereas its leaves come in contact with the vapor and the rain in the atmosphere; but Linsser considers that the relation of the plant to the water in the soil is the important feature that decides as to the development of the peren-

nial plants of temperate regions, which are those considered in his second memoir. So he leaves the study of atmospheric vapor and plant life to the future, while confining himself at present to the relation between rainfall and the periodic phenomena of vegetation.

It is not necessary to reproduce the tables of normal monthly rainfall given by Linsser for each of his stations, and generally based upon many years of observations. Of course, these numbers expressing the local rainfalls are, as is well known, less directly applicable to a neighboring locality than are the mean monthly temperatures, and they must be used with correspondingly less confidence.

The constant fractional part of the annual sum total of heat, as previously established by Linsser, afforded him a valuable suggestion or a working hypothesis as to the relation between the life of the plant and other factors, such as sunshine, rainfall, nutrition, and in fact every factor that influences the life of the plant. If, namely, a plant utilizes one-tenth of its annual cycle of heat in order to bring it to the leafing stage, why may it not also require one-tenth of its annual cycle of rain or sunshine or some similar constant fractional part? Now, in the development of a plant there is necessary, first, the material, viz, rainfall, or irrigation water with the nutrition contained therein, and on the other hand one or more forces, such as sunshine and heat, by the help of which the plant can utilize that material in its process of assimilation. The different phases of the development of the plant, such as the appearance of the blossoms and the ripening of the fruit, are work accomplished; in this work the water supplies the principal material, while the heat, says Linsser, plays the rôle of the principal force; but the work of the plant—that is to say, its progressive development—will only be in proportion to the force, so long as the latter finds a sufficient quantity of material present to insure the complete utilization of the force. Evidently a force that is competent to convert a certain quantity of material to the use of the plant will only be half utilized if only half of this quantity of material is present. In other words, the development of the plant goes on in proportion to the quantity of heat only so long as the plant has at its disposal the maximum quantity of material that can be worked over by this heat.

Therefore any further investigations as to the relation of the life of a plant to its external factors must necessarily consider the distribution of material with reference to the distribution of heat. In our present case it is the distribution of the quantity of rain with reference to the heat, and if such relative distribution is not considered then its omission is only permissible under the assumption that during the whole period of vegetation the material necessary to the growth of the plant is always present in such quantity that at any

moment the force then acting can be completely utilized. This assumption as to rainfall is actually fulfilled over by far the largest part of the European area hitherto studied by Linsser.

Of course, we can not speak of absolute quantities of heat or nourishing material. We have to do only with their relative distribution during the period of vegetation—that is to say, with the ratio of the quantity of material ( $f$ ) to the quantity of heat ( $w$ ). If we consider that the quantity of material that a definite quantity of heat is able to work up for the use of the plant is directly proportional to this quantity of heat, then the ratio  $f/w$  will have for each plant and phase a certain definite value that may be called the most favorable ratio and for which value the material on hand is completely used up by the heat or active force that is present. If the material that is present is not sufficient for the heat, then  $f/w$  is smaller than this most favorable value, and in this case the material is completely used up; but a portion of this heat remains unused and wasted. If, on the other hand, the heat is not sufficient to use up all the material, then  $f/w$  is too large and the heat is completely used, but a portion of the material is wasted.

The fractional portion of the annual sum total of heat that is needed to bring a plant up to any stage of vegetation is by Linsser called the “physiological constant” for that phase and plant, and is constant wherever the plant is acclimatized. The ratio  $f/w$ , as compiled by him month by month for each of his stations, is a local climatic constant, which is large when the climate is favorable to the growth of the plant—that is to say, when there is abundance of rain—but is small when the climate is more or less unfavorable to the plant—that is to say, when the summer rains are deficient.

The vegetation of the whole world is, according to Linsser's views, to be divided into zones (A, B, C, D, E, F), according to the annual distribution of the monthly ratios  $f/w$ . Thus in the highest latitudes (Linsser's zone A) and in the greater part of the European region covered by Linsser's researches, there is during the entire year a deficiency of heat, but a sufficiency of moisture and of material to employ all the heat force that is available. In the Steppes of Russia, however, there is a deficiency of moisture during the summer and autumn, and the fraction  $f/w$  becomes quite small for the zone B. The other localities that have a wet and a dry period annually may be divided into three classes, viz, C, where the drought comes during the months of July and December; D, where the drought comes during the months of January and June, or E, where there are two annual droughts, January to March and June to August. This latter arrangement is shown in Madeira in the vegetation of certain kinds of apples. Finally, we may have in zone F a perpetual abundance

of both heat and moisture, in which case all annual periodicity disappears and the plant goes through its cycle of vegetation independent of the months of the year, as in the warm and rainy regions of Java.

As before said, the absolute value of the ratio  $f/w$  need not be considered at present, and in fact it changes with the units of time, of temperature, or rainfall, etc. Linsser divides the depth of the monthly rainfall, expressed in Paris or French lines, by the average temperatures of the respective months expressed in degrees Centigrade.

In order to ascertain which of his European stations lies in the zone A and which in the zone B it is necessary to adopt some limiting value for the ratio  $f/w$ , and to this end Linsser examines these ratios in connection with the phenomena of plant life, adopting the principle that as two plants from different places, accustomed to different quantities of heat, behave differently when they both receive the same quantity of heat, so also two plants from places having different distributions of rain will behave differently and arrive at the same phase at different times when they are brought into the same place or under the same local climatic influences as to moisture and temperature.

In order to decide as to the limiting value Linsser studies the ratios for the hottest months of the year, which all relate to the ripening phases of vegetation, and finds that for the units of measure adopted by him the value of ratio  $f/w$ , that represents approximately a dividing line between the stations that have an abundance of rain in summer relative to the summer heat and those that have little rain relative to the heat, is 1.2. I have indicated in the preceding table by the letters A and B the stations that have  $f/w > 1.2$  and  $f/w < 1.2$ , and which Linsser puts into his zones of abundant and scanty summer rains, respectively.

I give in the following table some of the more striking and permanently important results of Linsser's computations. His original work, based on about 30,000 observations, gives for each of his 31 stations and for 118 species of plants and for each of the three phases—leafing, blossoming, and ripening—the ordinary phenological constant or sum total of mean daily temperatures above 0° C., and also his own physiological constant, which is the ratio of this sum total to the annual sum total for the station. In the following summary I give the physiological constant as it results from the average of all the individual stations in the zone A; but for the sake of quicker comparison between the results for zones A and B the summary gives not the physiological constant for B, but its departure or difference

from that of zone A. For example, for *Acer campestre* the constant in zone A for leafing is 0.131, but for zone B it is less than that by 0.039, and would therefore be 0.092.

*Tabular summary of Linsser's results.*

Orders, suborders, and species.	Physiological constants for zone A.			Departures of physiological constants for zone B from those of zone A.		
	Leaf-ing.	Bloom-ing.	Ripen-ing.	Leaf-ing.	Bloom-ing.	Ripen-ing.
<b>Sapindaceæ (Acerineæ):</b>						
<i>Acer campestre</i> .....	0.131	0.170	0.803	-0.039	-0.072	-0.098
<i>Acer platanoides</i> .....	.100	.105	.875	-.020	-.019	-.313
<i>Acer pseudoplatanus</i> .....	.132	.161	.808	-.029	-.067	-.110
<i>Acer tataricum</i> .....	.132	.225	.752	.....	-.053	-.132
<b>Sapindæ:</b>						
<i>Aesculus hippocastanum</i> .....	.107	.187	.821	-.030	-.054	-.064
<i>Aesculus lutea</i> .....	.114	.196	.860	.....	.....	.....
<i>Aesculus pavia</i> .....	.132	.232	.890	.....	.....	.....
<b>Cupuliferæ (Betuleæ):</b>						
<i>Alnus glutinosa</i> .....	.068	.047	.930	-.012	-.019	-.199
<b>Amygdaleæ:</b>						
<i>Amygdalus communis</i> .....	.099	.093	.768	-.017	-.010	-.068
<i>Amygdalus persica</i> .....	.101	.071	.684	-.017	-.009	-.051
<b>Aristolochiaceæ:</b>						
<i>Aristolochia siphon</i> .....	.125	.243	.....	-.035	-.053	.....
<b>Berberidaceæ:</b>						
<i>Berberis vulgaris</i> .....	.092	.188	.748	-.026	-.036	-.182
<b>Cupuliferæ (Betulaceæ):</b>						
<i>Betula alba</i> .....	.112	.116	.743	-.034	-.050	-.010
<i>Betula alnus</i> .....	.121	.048	.875	.....	.....	.....
<b>Bignoniaceæ:</b>						
<i>Bignonia catalpa</i> .....	.185	.472	.889	-.059	-.092	.....
<b>Euphorbiaceæ:</b>						
<i>Buxus sempervirens</i> .....	.079	.087	.695	+ .071	-.013	.....
<b>Papilionaceæ:</b>						
<i>Caragana arborescens</i> .....	.084	.168	.649	+ .016	-.050	-.201
<b>Cupuliferæ:</b>						
<i>Carpinus betulus</i> .....	.110	.120	.....	-.020	-.035	.....
<b>Leguminosæ (Papilionaceæ):</b>						
<i>Cercis siliquastrum</i> .....	.149	.192	.836	-.009	-.080	-.026
<i>Colutea arborescens</i> .....	.105	.270	.762	-.045	-.065	-.257
<b>Tiliaceæ:</b>						
<i>Corchorus japonicus</i> .....	.061	.125	.....	+ .029	-.045	.....
<b>Cornaceæ:</b>						
<i>Cornus alba</i> .....	.086	.211	.518	-.016	-.032	-.058
<i>Cornus mascula</i> .....	.119	.045	.691	-.015	-.010	-.077
<i>Cornus sanguinea</i> .....	.092	.251	.738	-.012	-.042	-.125
<b>Cupuliferæ:</b>						
<i>Corylus avellana</i> .....	.095	.021	.710	-.028	-.006	-.105
<b>Pomaceæ:</b>						
<i>Cotoneaster vulgaris</i> .....	.078	.192	.586	-.068	-.063	-.231
<b>Rosaceæ:</b>						
<i>Cratægus coccinea</i> .....	.110	.225	.831	.....	.....	.....
<i>Cratægus oxyacantha</i> .....	.091	.210	.739	-.026	-.066	-.149
<b>Leguminosæ:</b>						
<i>Cytisus laburnum</i> .....	.117	.192	.705	-.027	-.050	-.151

## Tabular summary of Linsser's results—Continued.

Orders, suborders, and species.	Physiological constants for zone A.			Departures of physiological constants for zone B from those of zone A.		
	Leaf-ing.	Bloom-ing.	Ripen-ing.	Leaf-ing.	Bloom-ing.	Ripen-ing.
Thymelaeaceae (Daphnoidae):						
<i>Daphne laureola</i> .....	0.080	0.040	0.375	-----	+0.080	-----
<i>Daphne mezereum</i> .....	.081	.089	.433	+0.009	— .028	—0.168
Celastraceae:						
<i>Euonymus europaeus</i> .....	.110	.228	.852	— .086	— .078	— .282
<i>Euonymus latifolius</i> .....	.108	.192	.767	— .008	— .029	— .147
<i>Euonymus verrucosus</i> .....	.094	.253	.775	— .084	— .105	-----
Cupuliferæ:						
<i>Fagus castanea</i> .....	.148	.352	.804	— .088	-----	-----
<i>Fagus sylvatica</i> .....	.152	.188	.737	— .050	— .053	— .217
Oleaceae:						
<i>Fraxinus excelsior</i> .....	.161	.186	.845	— .049	— .050	— .365
<i>Fraxinus ornus</i> .....	.156	.184	.806	— .066	— .050	-----
Leguminosae (Papilionaceae):						
<i>Gleditschia triacanthos</i> .....	.176	.310	-----	— .086	— .094	-----
Araliaceae:						
<i>Hedera helix</i> .....	.120	.779	-----	— .020	— .097	-----
Elaeagnaceae:						
<i>Hippophae rhamnoides</i> .....	.116	.133	.630	— .053	— .003	-----
Ilicineae (Aquifoliaceae):						
<i>Ilex aquifolium</i> .....	.085	.281	-----	+ .055	— .111	-----
Juglandaceae:						
<i>Juglans nigra</i> .....	.202	.227	.798	— .102	— .077	-----
<i>Juglans regia</i> .....	.161	.196	.794	— .059	— .080	— .046
Oleaceae:						
<i>Ligustrum vulgare</i> .....	.082	.323	.841	— .017	— .055	— .121
Magnoliaceae:						
<i>Liriodendron tulipifera</i> .....	.142	.343	.810	— .052	-----	-----
Caprifoliaceae:						
<i>Lonicera caprifolium</i> .....	.050	.259	.670	— .030	— .080	-----
<i>Lonicera periclymenum</i> .....	.049	.286	.663	— .009	— .033	— .133
<i>Lonicera symphorycarpos</i> .....	.072	.265	.766	-----	-----	-----
<i>Lonicera tatarica</i> .....	.048	.177	.587	— .008	— .040	— .227
<i>Lonicera xylosteum</i> .....	.085	.190	.624	— .018	— .054	— .254
Pomaceae:						
<i>Mespilus germanica</i> .....	.130	.246	.921	— .070	— .068	— .121
Magnoliaceae:						
<i>Magnolia yulan</i> .....	.137	.108	.880	— .037	— .008	-----
Urticaceae:						
<i>Morus alba</i> .....	.166	.249	-----	— .057	— .088	-----
<i>Morus nigra</i> .....	.169	.267	.566	— .059	— .027	— .158
Saxifragaceae:						
<i>Philadelphus coronarius</i> .....	.062	.265	.746	— .006	— .048	— .110
<i>Philadelphus latifolius</i> .....	.101	.316	.757	-----	-----	-----
Coniferae (Aletineae):						
<i>Pinus larix</i> .....	.068	.098	-----	— .019	— .028	-----
Platanaceae:						
<i>Platanus occidentalis</i> .....	.168	.276	.930	— .081	— .119	-----

## Tabular summary of Linsser's results—Continued.

Orders, suborders, and species.	Physiological constants for zone A.			Departures of physiological constants for zone B from those of zone A.		
	Leaf-ing.	Bloom-ing.	Ripen-ing.	Leaf-ing.	Bloom-ing.	Ripen-ing.
<b>Salicaceæ:</b>						
Populus alba .....	0.124	0.072	0.517	-0.080	-0.081	-----
Populus balsamifera .....	.108	.068	.800	-----	+ .002	-----
Populus canescens .....	-----	.074	-----	-----	- .028	-----
Populus fastigiata .....	.127	.080	-----	-----	- .050	-----
Populus nigra .....	.107	.093	.480	+ .010	- .024	-0.250
Populus tremula .....	.139	.050	.175	- .081	- .011	- .095
<b>Amygdaleæ:</b>						
Prunus armeniaca .....	.104	.068	.621	- .016	+ .002	- .199
Prunus avium .....	.090	.091	.421	-----	+ .001	- .144
Prunus cerasus .....	.110	.123	.419	- .037	- .040	- .053
Prunus domestica .....	.107	.111	.659	- .013	- .009	- .095
Prunus padus .....	.091	.150	.545	- .036	- .042	- .185
Prunus spinosa .....	.093	.119	-----	- .036	- .040	-----
<b>Rutaceæ:</b>						
Ptelea trifoliata .....	.156	.292	-----	- .026	- .052	-----
<b>Rosaceæ:</b>						
Pyrus communis .....	.107	.123	.728	- .033	- .022	- .227
Pyrus cydonia .....	.103	.186	.827	+ .027	- .037	- .063
Pyrus japonica .....	.053	.074	.875	-----	-----	-----
Pyrus malus .....	.113	.160	.815	- .036	- .057	- .183
Pyrus spectabilis .....	.091	.152	.827	-----	- .052	-----
<b>Cupuliferæ:</b>						
Quercus pedunculata .....	.150	.190	.849	- .050	- .055	- .111
Quercus robur .....	.130	.188	-----	+ .010	-----	-----
Quercus sessiliflora .....	.186	.225	.870	- .076	- .075	-----
<b>Rhamnaceæ:</b>						
Rhamnus cathartica .....	.114	.230	.800	-----	- .098	-----
Rhamnus frangula .....	.128	.246	.777	-----	- .089	- .367
<b>Anacardiaceæ:</b>						
Rhus cotinus .....	.176	.319	.560	- .093	- .136	- .146
Rhus typhina .....	.147	.416	-----	- .037	- .110	-----
<b>Saxifragaceæ:</b>						
Ribes alpinum .....	.072	.111	.525	-----	- .031	-----
Ribes grossularia .....	.051	.099	.454	- .090	- .033	- .073
Ribes nigrum .....	.089	.124	.438	-----	-----	-----
Ribes rubrum .....	.075	.112	.414	- .032	- .086	- .117
<b>Leguminosæ:</b>						
Robinia pseudo-acacia .....	.158	.269	.827	- .048	- .067	- .092
Robinia viscosa .....	.147	.288	-----	-----	- .048	-----
<b>Rosaceæ:</b>						
Rosa canina .....	.069	.297	-----	+ .011	- .068	-----
Rosa centifolia .....	.111	.297	.794	- .044	- .050	- .054
Rosa gallica .....	.104	.315	-----	- .074	- .101	-----
Rubus idæus .....	.082	.256	.460	- .035	- .072	- .065
Rubus odoratus .....	.126	.348	.480	-----	- .042	-----
<b>Salicaceæ:</b>						
Salix alba .....	.122	.115	.294	- .062	- .087	-----
Salix caprea .....	.111	.057	.236	- .021	- .027	- .116
Salix fragilis .....	.097	.116	.840	-----	-----	-----



## Tabular summary of Linsser's results—Continued.

Orders, suborders, and species.	Physiological constants for zone A.			Departures of physiological constants for zone B from those of zone A.		
	Leaf-ing.	Bloom-ing.	Ripen-ing.	Leaf-ing.	Bloom-ing.	Ripen-ing.
Caprifoliaceæ:						
<i>Sambucus ebulus</i> .....	0.105	0.361	0.750	.....	+0.005	—0.150
<i>Sambucus nigra</i> .....	.067	.280	.674	—0.029	— .066	— .053
<i>Sambucus racemosa</i> .....	.069	.132	.526	— .039	— .018	— .173
Rosaceæ:						
<i>Sorbus aucuparia</i> (or <i>Pyrus aucuparia</i> ) .....	.066	.202	.646	— .028	— .047	— .189
<i>Spiræa bella</i> .....	.064	.227	.790	.....	.....	.....
<i>Spiræa hypericifolia</i> .....	.109	.199	.600	— .059	— .077	— .290
<i>Spiræa lævigata</i> .....	.050	.164	.680	.....	.....	.....
<i>Spiræa salicifolia</i> .....	.077	.330	.820	.....	— .156	.....
<i>Spiræa sorbifolia</i> .....	.018	.381	.850	+ .052	— .156	— .270
Sapindaceæ:						
<i>Staphylea pinnata</i> .....	.094	.172	.713	+ .006	— .041	.....
<i>Staphylea trifoliata</i> .....	.117	.180	.734	.....	.....	.....
Saxifragaceæ:						
<i>Syringa persica</i> .....	.086	.183	.803	— .018	— .036	.....
<i>Syringa vulgaris</i> .....	.078	.174	.740	— .005	— .049	— .025
Coniferae:						
<i>Taxus baccata</i> .....	.127	.086	.748	+ .013	— .029	— .128
Tiliaceæ:						
<i>Tilia europæa</i> .....	.110	.385	.....	.....	.....	.....
<i>Tilia grandifolia</i> .....	.124	.366	.772	.....	— .046	— .242
<i>Tilia parvifolia</i> .....	.136	.417	.806	— .032	— .087	— .108
Urticaceæ:						
<i>Ulmus campestris</i> .....	.127	.072	.244	— .043	— .028	— .067
<i>Ulmus effusa</i> .....	.113	.063	.236	— .003	— .015	— .066
Caprifoliaceæ (Lonicerae):						
<i>Viburnum lantana</i> .....	.091	.177	.706	— .051	— .057	— .152
<i>Viburnum opulus</i> .....	.100	.233	.780	— .027	— .075	— .258
Vitaceæ:						
<i>Vitis vinifera</i> .....	.164	.366	.821	— .051	— .076	— .108

In the original, from which the foregoing abstract is copied, Linsser gives the so-called probable error or the limit of uncertainty as deduced from the agreement among themselves of the numerous individual determinations of the physiological constants in zone A, whereas the mean values alone are given in our summary. It appears that the uncertainties are larger for the ripening phase than for the leafing and blooming phases, if we consider only their absolute values, but decidedly smaller if we consider their relative values. In general the uncertainty of the constant for leafing is about one-twentieth of its own value, the uncertainty of the constant for blooming is about one-fortieth of its own value, and the uncertainty of the constant for ripening is about one-fiftieth of its own value.

The values of the constants, as deduced from stations that lie in the dry zone B, vary much more than those in zone A; but this is a necessary consequence of the law of growth, since in such dry regions the quantity of heat required to produce a given phase ceases to be a simple constant and becomes a complex function of the available heat and moisture and depends upon the individual ratio  $f/w$  at each station. It will of course be noticed that, with few exceptions, the figures in the columns of departures are negative, thereby indicating that the quantities of heat actually utilized by plants in the dry localities in zone B are less than the quantities utilized by the same plant when it has an abundance of moisture in zone A. Most of the 17 positive figures among these departures relate to the period of leafing, and many of them are but little larger than the limit of uncertainty deduced by Linsser for the respective plants.

All of the plants investigated by Linsser belong, as is seen by the above list of names, to the exogens. They are also perennials, but his intention was to extend this investigation to the herbaceous annuals, and a large mass of work in this direction had been accomplished before his untimely death in 1871.

The conclusions drawn by Linsser from the data, as summarized in his published tables, may be presented as follows:

Although the general fact above mentioned, that plants growing in regions that have scant summer rains utilize less heat and less moisture to produce a given phase of development than similar plants having the same quantity of heat at their disposal with plenty of rain during the summer, might be considered as only a further consequence easily deduced from the principle that underlies the theory of Linsser's physiological constant, yet we may also consider the fact as one established empirically and seek for the most probable explanation. Any general relation between the vital phenomena of plants and their external influences can, according to the ideas established in Linsser's first memoir, be looked upon either as due to temporary influences or as a consequence of the habits of the plant. If we adopt the former view, then the cause of the accelerated development of plants in zone B will consist in the fact that from the beginning of vegetation onward one or more accelerating forces have come into play, the intensity and duration of whose action is greater for stations in zone B than in zone A. Such accelerating forces may consist in a greater quantity of heat or of sunshine or possibly other influences. But when we come to examine the temperature curves for stations in the two zones we see at once that heat alone can not be considered as the stimulating force. A similar comparison shows that rainfall during the growing season can not be the stimulus. Again, stations such as Parma and Pessan show that great differences in

sunshine alone fail to give a sufficient explanation. Finally, a natural and sufficient explanation is found in the study of the relation of the rainfall in summer to the given climatic conditions, as has already been done in the study of the heat; it is not the rainfall of the spring months that stimulates the plant, but it is the drought of the succeeding summer, or, as it were, the knowledge of that approaching drought which stimulates the plant to hasten and complete its development in the springtime or earliest summer. The plants of the north are accelerated because of the rapidly approaching autumn; the plants of the highlands because of the shortness of the approaching summer; the plants of the steppes and of regions with rainless summers hasten in order to have their work finished when the time arrives at which their activity should come to an end. The plants at localities in our zone B complete their labors in the springtime because of the drought of the coming summer; under almost the same external conditions the plants at Parma hasten their development while those at Venice live leisurely along; the plants at Vienna, Breslau, and Kief accelerate their growth, while the same plants at Heidelberg, Görlitz, and Orel live leisurely.

The problem, so often discussed, of the reforestation of the steppes is thus referred back to another more definite problem, viz., the acclimatization in the steppes of those plants whose normal cycle of vegetation in their native locality is such that when transplanted to the steppes these processes, especially the blossoming and leafing, can go on with sufficient rapidity to be completed before the beginning of the hot, dry summer. Quite similarly the problem of cultivation of fruit in those regions can be thus exactly defined. Thus Helmersen states that experiments with fruit trees brought from Hamburg to Orenburg entirely failed. But here we have to do with a double violation of the theory, since the plants brought from Hamburg came to a locality having a much smaller annual sum of heat and were not yet adjusted to the dryness of the Orenburg summers, wherefore they continued living at Orenburg according to the easy habit acquired at Hamburg. Linsser suggests that success would be much more likely if plants were taken to Orenburg from Bokhara or Khiva, where the extraordinary rapidity of development, on account of the great dryness of the summer following after a rainy spring is well known.

Further questions as to the temporary influence of rainfall during any part of a cycle of vegetation must be investigated by studying the life of plants at localities having very different climates.

After studies on the development of vegetation in various climates throughout the world, in all of which the rainy season is the blossom-

ing time, while the dry season is the ripening time, Linsser gives the following general conclusions:

There are two especial laws regulating the life of every individual plant, (1) the individual habit; and (2) the principle of economy. The application of these principles explains and gives us a better comprehension of the course of vegetation under the equator as well as near the pole.

The principal factors in the life of plants that we have thus far considered are heat and moisture. If the former is that whose periodicity gives warning of the necessity of economy, then the whole life of the plant is intimately dependent on the course of this heat, as in the extreme north and the greater part of the Temperate Zone where the moisture is otherwise sufficient. If it is the moisture that is subject to large periodical changes and the question of sufficiency of heat becomes unimportant because of its uninterrupted abundance, then the cycle of vegetable life depends upon the periodicity of this moisture, as in Madeira. If, finally, the variations of the climate are such that there is sometimes insufficient heat and moisture, then the necessity of economy in the use of both of these materials is enforced, and in the course of the year the plant seeks to develop as far as possible in accordance with both these necessities, as in the Steppes of southern Russia and near Bokhara and in isolated shady locations such as mountain sides.

The law of fractional parts of the total annual quantity of heat, as demonstrated in Linsser's first memoir, is therefore now seen to be only a special case, for northern and temperate latitudes, of the general proposition just enunciated. The former was the first approximation toward a rational theory of the periodical phenomena of vegetation, just as this more general proposition is the second approximation.

We have thus far studied principally the differences in the life of plants due to differences of climate in different localities. It still remained for Linsser to study the peculiarities of the same plants in different years in the same locality, to which end his manuscript material already offered a sufficient basis.

Of the questions proper to be considered in this second category, viz, the study of plant life as depending on temporary variations of local climates, Linsser enumerates the following as having already been taken up by him, viz: (1) The influence of cloudiness, insolation, and atmospheric pressure; (2) the especial influence of the various distributions of rain on the individual periods of vegetation; (3) the relation of the length of the day and the night, as also of light itself, on the plant; (4) the influence of the nonperiodic variations of temperature; (5) the influence of cold or warm winters on the subsequent summer's growth; (6) the investigation of the sums of tem-

perature for the same phases of plant life from year to year, and the reason of their variations. On this last point he concludes by stating that it is well known these sums do vary from year to year for each phenological epoch. For the present he states only that these temperature sums are not only apparently, but in reality, not constant, and from his preliminary work for this second series of studies the most important causes that determine the sum total had already become known to him. Without anticipating too much the course of further investigations, he states that studies already finished demonstrate that there should be differences annually in the temperature sums, as is evident from the following consideration: If seeds brought from Stuttgart to Christiania accelerate in successive generations in successive years because of the smaller sum total of heat in their new home, then exactly the same would occur if the plants remain in Stuttgart and we at that place offer them the sum total of heat peculiar to Christiania. That is to say, seeds that have ripened at any one place in colder years produce plants that develop more rapidly than do seeds from the same place but which were ripened in warmer years.

#### APPLICATION OF LINSSER'S RESULTS.

This application to each plant and each locality of the principle of economy which Linsser had established from the geographical distribution of plants offers to us by far the most important principle yet discovered and well established to guide us in the development of grains and plants appropriate to the vicissitudes of our climate. For instance, in general it is desirable to sow and plant so as to avoid the early autumn frosts and the late spring frosts—that is to say, to secure varieties of plants whose course of vegetation will be complete in the very short time that is free from danger of frost. Therefore, if we wish to develop plants that will ripen in the earliest summer, before the droughts destroy them, as in the region from Nebraska to Texas, then we have to remember that the seed perfected in Kansas in a dry year is already, by its own experiences, prepared to become the best seed for sowing in anticipation for the next dry year. The seeds raised in dry years should therefore always be preserved for sowing, as likely to be far more appropriate than any seed that may be brought from a distance, unless brought from a region where equally dry, short seasons prevail, as in southern Russia and Bokhara. The rule of sowing one year the seed raised the preceding year is, in general, not the best rule. By always utilizing as seed that which is raised in the driest years one may hope speedily to develop plants whose vegetating period will be so short that the crop will rarely be injured by the dry, hot winds of July. A similar rule holds good for any modification we desire to make in the seed. If we wish to

raise plants peculiarly fitted for wet climates or for cold climates, we begin with the seed that was ripened in wet or cold seasons.

I think that probably a further prosecution of Linsser's studies would have led to the conclusion that the influence of sunlight and diffuse sky light is the next important factor in vegetation, and that the quantity and quality of the seeds produced—that is to say, of the crop as distinguished from the mere epoch of ripening—depends upon the ratio of the nutrition carried up in the sap to the total intensity of sunshine. The grain harvests of the world may be divided into zones *a*, *b*, *c*, analogous to the phenological zones that Linsser has given, and in which the quantity of the harvests is large when the nutrition is sufficient to use up all the sunshine, but is small when either nutrition or sunshine is deficient. As the plant begins a new cycle so soon as the last is finished and usually is delayed by the speedy approach of winter cold or autumnal drought, therefore Linsser's laws would lead us to the conviction that by artificially regulating the temperature, moisture, sunshine, or artificial light, and the nutrition in the soil, we ought to be able to develop an ideal method of cultivation that should greatly increase the number of crops per year and the yield per acre, and especially so within small, limited areas that are protected by cover from injurious frosts.

The need of water for the varieties of plants and seeds usually cultivated has led to great engineering projects for irrigation, and the scarcity of natural rainfall has led to wholesale condemnation of many arid regions as being unfit for profitable agriculture, but the progress of knowledge now shows us that nature has a power at work gradually overcoming these disadvantages, and that man by taking advantage of her ways may profitably cultivate crops in extreme climates and soils, not so much by irrigation as by developing seeds and plants that suit the natural circumstances, just as our own ancestors developed our European grains from the grasses of Asia or our widespread maize from the weeds of Mexico. It is the duty of our agricultural experiment stations to lead the way in this evolution of new varieties quite as much as in the mere introduction or acclimatization and study of old varieties. Now that we have learned the secrets of Nature's method of evolution we must hasten to apply it to the needs of mankind.

DOVE.

In 1846 H. W. Dove wrote as follows:

In the tropical regions the mean temperature of any year differs but little from that of any other, but the quantity of rainfall differs largely. The result is that the yield of crops varies exceedingly, not only on lowlands that depend upon the periodical floods of the rivers, but also on the islands, where there are no large rivers. Therefore in these climates the agriculturist cares less about the temperature than about the rainfall.



In Europe, however, the connection between the temperature of the air and vegetation is so intimate that some investigators maintain that on the occurrence of a given temperature the plant enters at once upon a corresponding definite stage of development, while others maintain that in order to enter into this stage a definite sum total of heat must be received. Therefore the former determined the stages of development by the ordinates of the annual curve of temperature, while the latter determine them by the area of the space that is bounded by such ordinates. It is evident that if under a given latitude the temperature of the atmosphere is the principal factor, while under another latitude the moisture of the atmosphere is the principal factor, then neither of these should be entirely overlooked, but the part played by each must be examined. To this end the study of the geographical distribution of plants gives very little information. Again, the study of the influence of periodic variations of the atmosphere on plants is useless in the attempt to distinguish between the effects of temperature and moisture, because as a general rule the atmospheric conditions all attain their maxima and minima at about the same time. The study of the nonperiodic variations gives promise of greater success. But in studying the relation of temperature to vegetation the data given by thermometers hung in the shade, as to the temperature of the air, can have little to do with the life of the plant as compared with the temperature given by a thermometer exposed to the full sunshine by day and the radiation from the sky by night.

Dove then discusses the observations of maximum sunshine and minimum radiation thermometers made in the botanic garden at Chiswick, near London, from 1816 to 1840, and shows among other things that when the mean temperature of the air is low the freely exposed radiation thermometer is especially low, and when the average temperature is high the freely exposed solar thermometer is especially high. He then investigates the observations of earth temperature made by Quetelet, of Brussels, from 1834 to 1843, and shows that the upper layers of soil, whether dry or wet, have temperature variations parallel to those of the temperature of the air. He then studies the phenological observations of Eisenlohr at Karlsruhe from 1779 to 1830. These show that a plant enters into a definite stage of development when the air attains a definite degree of temperature rather than when the plant has received a definite sum total of heat, this conclusion being, of course, based upon the internal agreement of the computed figures for these fifty-one years of observations.

Analogous results were obtained by him by studying similar observations made in the State of New York and at Wurttemberg, Germany.

With regard to the influence of rainfall, Dove finds that it is not so plain as that of temperature, and that it is not so much the quantity of rainfall that is important as the frequency; too great fre-



quency is injurious, inasmuch as the cloudiness cuts off the influence of sunshine. The fact that years of low temperature are always years of poor crops is a fact that must be generally considered as a local phenomenon because of the simultaneous compensation as to temperature that is continually going on in contiguous localities.

#### HOFFMAN.

Prof. Dr. H. Hoffmann published, first at Giessen and afterwards in the *Memoirs of the Senckenberg Association at Frankfort* (Vol. VIII, 1872), the details of a work which he began in Giessen in 1866 on the relation between the development of plants and the temperature recorded by a maximum thermometer in full sunshine. Some account of that work and its subsequent continuation at Giessen is given in successive papers published in the *Journal of the Austrian Meteorological Association* (*Zeitschrift O. G. M.*) during the years 1868 to 1891. The detailed references to these will be found in the list of papers appended to this present report. Hoffmann's first conclusion, as stated in 1868, was that he had found a precise, intelligible, and comparable expression for the quantity of heat that is needed for the attainment of any definite phase of vegetation. He would take the sum of the daily maxima of a thermometer fully exposed to the sunshine. His first work at Giessen was done with a naked glass bulb, self-registering, mercurial, maximum thermometer, graduated to Réaumur's scale, attached to a wooden frame and set out in full sunshine 4.5 French feet above the soil or green sod in an open portion of the botanic garden at Frankfort. The exposure was indeed not perfectly free, but was such that the sun shone upon the thermometer from sunrise to 2 p. m. in January and until 4.30 p. m. in June. Hoffmann's summations begin with midwinter, or January 1, and he gives the sums of the positive daily maxima (i. e., above 0° Réaum.) up to the dates of leafing and flowering for 10 plants.

Apparently preliminary values are given in the *Journal of the Austrian Meteorological Society* for 1868 and 1869, but final values in the memoir published at Frankfort, 1872.

In the *Meteorologische Zeitschrift* for 1875 Hoffmann says that after four years' work at Giessen (1866-1869) his thermometer was broken. A new one was constructed by Dr. J. Ziegler, of Frankfort, in accordance with their mutual understanding; this had a mercurial bulb, but was very many times larger than the former, and therefore very much more sluggish. Observations with such instruments, graduated to accord with the Réaumur scale, were begun in 1875 by Hoffmann at the botanic gardens at Giessen, and by Ziegler at the gardens at Frankfort. In order to compare these two series together and to unite them with the earlier Giessen series the ratios of the sums as given by the earlier and the later thermometers for the same

plant were taken, and it was found that the ratios are very nearly the same for all plants; therefore the ratio given by the best series, viz, for *Lonicera alpigena* was taken as a standard and applied to the series for the other plants, so as to reduce all observations with the later thermometers back to agreement with what would have been given by the first thermometer had it not been broken. The ratios of the sums observed at Giessen with the new thermometer as compared with the sums observed at Frankfort, also with a similar new thermometer, agreed closely for all the plants, and as the two new thermometers agree closely with each other when placed side by side, it was assumed that the ratios thus obtained represent the reduction from the climate of Frankfort to that of Giessen. Adopting the same standard plant and the ratio of its sums for any place to its sums at Giessen as the standard ratio, all the sums for plants at that place can be reduced to what would have been given by the same plants at Giessen and to what would have been given by the first Giessen thermometer. Although these reductions are very arbitrary, yet the agreement of the sums thus computed for Giessen with those actually observed was quite close. But, as we shall see, subsequent years of observations have shown that such agreements do not always recur.

In the *Zeitschrift* for 1881 Hoffmann shows that it is not the low temperatures but the subsequent too rapid thawing that injures most plants; thus the hill stations suffered less at the close of a period whose lowest temperature was  $-31^{\circ}$  Réaum. than did the plants in the lowlands; the shady side of the tree suffered less than the sunny side. It is indifferent whether the sudden rise in temperature is caused by great solar rays or by a sudden warm wind; the sudden rise from  $-12^{\circ}$  Réaum. to  $+13^{\circ}$  Réaum. is as bad for plants as the sudden rise from  $-20^{\circ}$  Réaum. to  $+5^{\circ}$  Réaum.; the amount of injury is proportional to the extent and to the suddenness of the rise.

In the same volume of the *Zeitschrift* (p. 330) Hoffmann gives the results of observations at Giessen for 1880. He finds that the blossoming in springtime is so subject to disturbances by frost that the midsummer and autumnal phases of vegetation are more proper to show the accuracy of his methods. He finds that these later phases, as observed at Giessen (1866–1869), when reduced to the new standard thermometer at Giessen agree within 1 per cent with the actual observations of 1880 at that place. For plants that bloom in the spring he finds that if these are protected from injury by frost by placing them under glass covers there is then a better but still unsatisfactory agreement between the observations at Giessen and Frankfort. On computing the mean temperature of the air in the shade for the dates of blooming at Giessen he finds no apparent connection, so that from the date of blooming we can not infer the mean temperature of that day nor can we reason from the temperature to the date.

The sum total of daily maximum sun temperatures at Giessen is much more nearly constant.

In the *Zeitschrift* for 1882 Hoffmann gives the sums of the daily positive readings of his naked bright-bulb mercurial thermometer in the full sunshine; he also gives the sums of the temperature in the shade, and computes the average discrepancy or probable error of these numbers as deduced from their internal agreement year by year. He finds the probable uncertainty of the sums of maxima to be plus or minus 1 per cent and of the sums of shade temperatures to be plus or minus 10 per cent. These latter sums relate to low-lying stations, such as Vienna and Dorpat, and these discrepancies diminish very much when we consider high mountain stations, where the shade temperatures of course give much smaller sum totals. He recognizes that the advantage of using the shade temperatures lies in the greater comparability of the observations made at different stations and with different instruments, but that the sunshine method is also greatly improved if the thermometers are perfectly similar and properly compared together, as in the instruments made by Doctor Ziegler at Frankfort. (See the report of the Senckenburg Association, 1879–1880, p. 337.) Hoffman's observations with a variety of instruments convinced him that this difficulty as to instruments and exposures is not insurmountable. He collects comparative readings at several places and shows that the difference between the average temperatures in the sun and in the shade is larger at higher altitudes; thus at Giessen the average difference in summer at midday is  $5^{\circ}$  Réaum., and the whole range of the differences between sunshine and shade is from  $3^{\circ}$  to  $15^{\circ}$  Réaum. The corresponding average in the Hochgebirge, 7,000 feet, is never less than  $8^{\circ}$  Réaum. At the Bernina hospice, 8,113 feet, it is  $25^{\circ}$  Réaum. The average temperature of these mountain stations is  $16.4^{\circ}$  Réaum., corresponding to an elevation of about 6,000 feet. Similarly, J. D. Hooker observing a black-bulb thermometer in the sunshine in the Himalayas, found a difference of  $-15^{\circ}$  Réaum. at 7,400 feet elevation, as contrasted with  $4.4^{\circ}$  at sea level. R. S. Ball, also using a black bulb, finds a difference of  $18^{\circ}$  or  $20^{\circ}$  Réaum. in the Hochgebirge and of only  $3^{\circ}$  at Chiswick.

These differences show the effect of the great dryness and mechanical purity of the air in the Hochgebirge. Hoffmann considers the smoke and clouds above us as affecting the difference between the sun and shade thermometers, but says nothing of the earth's surface which completes the "inclosure" of the thermometer.

The date from which Hoffmann begins his summation for Giessen is January 1; but as it would seem more proper to begin with some definite phase of vegetation, therefore he investigates the accuracy with which we can determine the initial phase and the effect of errors therein upon the ultimate sums. By painting the buds of certain

trees and examining them very frequently Hoffmann seeks to determine how accurately the date of the beginning of vegetation or the flow of sap can be determined by the swelling of the buds and the visible cracking of the delicate pencil lines of paint. He finds that the date can be determined to within one day when spring comes on rapidly, but within eight days when it comes very slowly. The corresponding uncertainty or variability of the sums of the maximum sunshine thermometer from the swelling of the buds up to the date of the first blossom, for instance, for *Castanea vulgaris*, is 4 per cent while the uncertainty of similar sums, counting from January 1, is only 1 per cent. These and similar data are only deducible from observations made upon the same tree or bush from year to year; the variations are materially increased when different plants in different localities are observed; moreover, they are based upon observations for only four years, which period is not long enough to give a reliable value of the relative uncertainties. As in previous cases in making up these abstracts, I give Hoffmann's actual figures in the following summary, which I have compiled by collating the few observations published by him in the *Zeitschrift* during the years 1870-1890. I have selected only the few plants for which he has published the sums for several years or for two localities, so that comparisons may be made and a judgment arrived at as to the propriety of his method. It will be observed that Hoffmann has, when possible, observed the same tree or bush from year to year, so that the problem of the influence of heat is much more definite than when different plants or a general mass of plants is observed; but, on the other hand, single plants are more liable to irregularities produced by special disturbances which would exert no appreciable influence on the average of a large number of similar plants.

*Temperature sums at Giessen (Hoffmann's method) from the first swelling of the buds to the first blossom.*

[Z. O. G. M., Vol. XVII, 1882, p. 127. All in Réaumur degrees.]

Plant.	1866.	1867.	1868.	1869.
<i>Castanea vulgaris</i> .....	2,044	2,142	2,065	2,317
<i>Catalpa syringifolia</i> .....		2,149	1,984	2,547
<i>Lonicera alpigena</i> :				
First specimen .....		891	1,058	1,014
Second specimen .....		919	1,058	1,032
<i>Persica vulgaris</i> :				
First specimen .....	659	678	774	788
Second specimen .....	803	670	984	-----
<i>Syringa vulgaris</i> :				
First specimen .....	1,388	-----	1,815	1,248
Second specimen .....	1,299	-----	1,181	1,166
<i>Vitis vinifera</i> :				
First specimen .....	-----	-----	1,040	1,531
Second specimen .....	-----	-----	856	1,222

Temperature sums from January 1 to the date of first blossom (by Hoffmann's method) at Giessen and at Frankfurt.

[Z. O. G. M., Vol. X, 1875, p. 251, and Vol. XVI, p. 331. All in Réaumur degrees.]

Plant.	Giessen.				Frank- fort, 1875, ther- mometer B <sub>2</sub> .
	1866-1869, ther- mometer A.	1875, ther- mometer B.	1880.		
			Ther- mometer B <sub>1</sub> .	Ther- mometer B <sub>2</sub> .	
Lonicera alpigena.....	1,167	916	.....	.....	.....
Sambucus nigra.....	1,678	1,315	.....	.....	.....
Berberis vulgaris.....	1,377	1,091	.....	.....	1,110
Prunus avium.....	1,077	820	.....	.....	800
Syringa vulgaris.....	1,393	1,091	.....	.....	.....
Aesculus hippocastanum.....	1,317	1,069	.....	.....	1,065
Vitis vinifera.....	2,600	1,995	2,697	2,603	.....
Prunus spinosa.....	.....	819	.....	.....	822

Temperature sums (by Hoffmann's method) at Giessen from January 1 to first blossom, for plants that blossom in midsummer and autumn.

[Z. O. G. M., Vol. XVI, p. 331, and Vol. XVII, p. 130 ; M. Z., Vol. I, p. 407, and Vol. III, p. 546.]

Plant (always same stock).	Thermometer A, 1866-1869.	Thermometer B <sub>1</sub> .		Thermometer B <sub>2</sub> .						
		1880.	1881.	1880.	1881.	1882.	1883.	1884.	1885.	1886.
Aesculus macrostachya...	3,353	3,504	3,479	3,191	3,254	3,929	3,846	3,639	3,546	3,556
Aster amellus.....	3,930	4,091	4,003	3,753	3,768	4,522	4,569	4,363	.....	.....
Lilium candidum.....	2,710	2,872	2,855	2,603	2,639	3,112	3,228	3,010	.....	.....
Linosyris vulgaris.....	4,033	4,091	4,260	3,753	4,040	4,555	4,670	4,502	.....	.....
Plumbago europaea.....	5,318	5,495	5,261	5,054	5,017	.....	.....	.....	5,386	5,494
Pulicaria dysenterica.....	3,381	3,618	3,263	3,753	3,045	.....	.....	.....	.....	.....

The contrast between the ordinary spring of 1881 and the very early spring of 1882 with its preceding warm winter, affords a test of the question as to how much the thermal constant is liable to change with the variations in the seasons. Hoffmann finds that although the first blossoms in the spring of 1882 occurred fifteen days earlier than usual, yet the sums of the maximum temperatures since January 1 were not much changed. The figures as given by him (Z. O. G. M., Vol. XVII, p. 460) are reproduced as follows:

Plant.	Thermal sums.		Date of blossoming.	
	1881.	1882.	1881.	1882.
Carpinus betulus.....	1,159.7	1,134.6	Apr. 19	Apr. 2
Larix europaea.....	789.9	759.9	Mar. 30	Mar. 15
Lonicera alpigena.....	1,471.7	1,490.4	May 6	Apr. 19
Prunus spinosa.....	1,159.7	1,091.6	Apr. 19	Mar. 31
Ribes grossularia.....	1,086.5	1,091.6	Apr. 16	Mar. 31
Crataegus oxyacantha.....	1,681.6	1,732.5	May 15	Apr. 30
Sorothamnus vulgaris.....	1,790.8	1,751.9	May 20	May 1
Berberis vulgaris.....	1,681.6	1,751.9	May 15	May 1

Many of the plants observed by Hoffmann show such discordant sums from year to year as to prove that his method has no meaning for them, but for others the agreement is such that he recommends them to be observed in connection with the observations of the sunshine thermometer, as follows:

For the following plants observe the temperature sums from the first swelling of the buds to the first flower blossom: *Castanea vesca*, *Bupleurum falcatum*, *Corydalis fabacea*, *Dianthus carthusianorum*, *Lonicera alpigena*, *Salix daphanoides*, *Syringa vulgaris*, *Amygdalus nana*, *Alnus incana*, *Alnus viridis*, *Atropa belladonna*, *Betula alba*, *Crataegus oxyacantha*, *Larix europaea* (up to the date when the pollen first falls from the anthers), *Ligustrum vulgare*, *Lonicera tatarica*, *Prenanthes purpurea*, *Prunus padus*, *Prunus spinosa*, *Rhamnus frangula*, *Ribes aureum*, *Rosa arvensis*, *Rosa alpina*, *Salix caprea*, male (for the catkin, or the flowers of the willow, the beginning of pollination, as ascertained by a light stroke on the flower, is to be considered as the date of the first blossom).

Hoffmann also applies his summation of sunshine maxima temperatures to the interval from January 1 to the ripening of the fruits and shows an excellent agreement between the numbers for 1880 and those for 1881 at Giessen.

In the Zeitschrift for 1884 Hoffmann gives his results for 1882, 1883, and 1884 as collected in the preceding table and says that the vexed question of the thermal constant for vegetation is still far from being settled; either temperature and vegetation are independent of each other, which no one can easily believe, or they stand to each other in a relation for which the correct expression is still unknown. Pfeffer in his Pflanzen Physiologie (Vol. II, p. 114) has stated that the approximate uniformity of the sums of temperature, from year to year, can only mean that, in general, for each year the heat received from the sun amounts to about the same sum total for the same date annually; but this is not in strict accordance with facts, for if it were true a small change in the date should make a small change in the sums, which is not always the case. Thus, if for *Linosyris vulgaris* the dates of blossoming are August 15, 18, or 20, the sums from January 1 for different years will be as follows:

Year.	Aug. 15.	Aug. 18.	Aug. 20.
1882.....	4,555	4,637	4,698
1883.....	4,597	4,670	4,728
1884.....	4,368	4,452	4,500

From these figures we see that the sums vary from year to year quite independently of the change of date.

The thermometer B<sub>1</sub>, similar to B<sub>2</sub>, having been sent to Upsala for observations at that place, it gave from January 1 to the first blossom



sums that agree so well with those found at Giessen that Hoffmann thinks no better can be expected.

In the *Zeitschrift* for 1885 Hoffmann continues to give the comparative observations at Giessen and Upsala, and remarks that the question is not as to whether his method is correct and the others are wrong, but as to which of all methods is even a little better than the others. Of these others only one can, he thinks, be compared with his own, viz, that of Karl Fritsch, who takes the sum of all positive mean daily shade temperatures. Hoffmann applies Fritsch's method to the observations at Giessen and Upsala and finds the argument not in its favor. He also tries another form of thermometer, viz, the so-called black bulb in vacuo, but finds it too sensitive, which he thinks is because its bulb is too small.

In the *Zeitschrift* for 1886 (p. 546) Hoffmann gives a summary of observations at Giessen and Upsala during 1886. In general the sums are smaller at Upsala and so also for high Alpine stations. He is thus led to the laws established by Karl Linsser, as published in St. Petersburg in 1867 and 1869, which laws he expresses as follows: "Every wild plant has in the course of time so adapted itself to the surrounding local climate that it utilizes this climate to the best advantage. For any given phase of vegetation it uses a certain proportional part of the available annual sum total of heat. Thus, if the annual sum at Venice is 4,000 and if the corresponding sum at St. Petersburg is 2,000 and if the plant utilizes one-fourth in order to bring it to the flowering stage, then it will require 1,000 at Venice and 500 at St. Petersburg." From Linsser's law he concludes; (1) plants that have been raised in the north and are transplanted to the south reach their phenological epochs earlier than plants already living there, while southerly plants carried to the north are retarded as compared with those already acclimatized; (2) plants raised on colder highlands when transplanted to the warmer lowlands have their epochs accelerated as compared with those already domesticated; plants raised in the lowlands and transplanted to the colder highlands develop more slowly than the acclimatized plants.

In the *Zeitschrift* for 1886 (p. 113) Hoffmann determines the relative retardation of vegetation as determined by the dates of the first blossom of several plants at different altitudes. The result is for the *Pyrus communis* (pear tree) and allied varieties a retardation of 3.7 days per 100 meters, and corresponding to this a retardation of 2.8 days per 1° of latitude. The analogous data for *Pyrus malus* (apples) are 2 days per 100 meters and 4.4 days per 1° of latitude. Charts are given showing by means of isophenological lines the gradual progress northward of the development of vegetation as spring advances.



In Petermann's Geog. Mitth. for 1881 Hoffmann gives a general phenological chart for central Europe showing the acceleration or retardation of the phases of vegetation with respect to Giessen.

In the Zeitschrift, 1882, Vol. XVII, page 457, Hoffmann gives the results of his study of observations collected by Karl Fritsch, showing the dates of blossoming and ripening of fruits in Europe, as reduced to the latitude and altitude of Giessen; and, second, the thermal constant by Hoffmann's method from observations at Giessen for the years 1881 and 1882, as collated in the preceding table. He also shows that the advance of vegetation in the early and very warm spring of 1882 did not materially diminish the sums total of maximum temperatures, the figures for which I have reproduced in the preceding table (p. 240).

#### MARIÉ-DAVY.

The extensive researches conducted at the observatory of Montsouris (Paris) are scattered through many annual volumes, from which I have culled sufficient to show the views held by Marié-Davy and his coworkers, who distinguish very clearly between thermometry and actinometry, and attempt to determine separately the constant amounts of air temperature and of sunshine which constitute the total molecular energy needed to develop the plant.

In his Annuaire for 1877 Marié-Davy quotes from Tisserand (1875) and Schuebeler (1862) the results of a series of observations on the culture of grain in Europe. Special praise is given to the records from Norway and to the high state of education among the Norwegian farmers. The durations of the periods from sowing to ripening are as follows:

Locality.	Latitude.	Mean annual temperature.	Sowing to ripening.		
			Spring wheat.	Spring rye.	Four-row barley.
	° N.	° C.	Days.	Days.	Days.
Halsno .....	59.47	6.8	133	139	117
Bodo .....	67.17	8.6	121	118	102
Strand .....	68.46	2.9	115	116	98
Skibotten .....	69.28	2.8	114	113	98
Algiers .....	36.45	.....	142	.....	.....
Paris (Fouilleuse) .....	48.50	.....	139	.....	.....

For other plants—oats, peas, beans, vetches, etc.—the duration of the vegetating period diminishes in a similar manner as the latitude increases or as the temperature diminishes; therefore we can not assume at once that warmth hastens the ripening, for in this case cold appears to hasten it. I say “appears,” because with the cold comes in another influence, viz, the amount of sunshine. Thus as we go

northward we have a greater amount of possible sunshine during the growing period, although the actual sunshine is very materially diminished by the quantity of cloud and fog. Tisserand calls attention to the maximum possible duration of sunshine as given in the following table for the season of spring wheat from sowing to ripening:

Latitude north.	Maximum sunshine duration.	Corresponding locality.
° '	Hours.	
48 30	1,996	Alsace.
50 0	1,795	Christiania.
50 30	2,187	Halsno.
67 0	2,376	Bodo.
68 00	2,472	Strand.
69 30	2,486	Skibotten.

These numbers of possible hours of sunshine should be diminished to actual hours of sunshine on account of cloudiness. Moreover, actual actinometric observations would have shown that owing to the atmospheric absorption the efficiency of the sunshine is less at low altitudes and, therefore, at high latitudes. But in the absence of fundamental climatic data Tisserand is probably correct in concluding that the temperature of the air has apparently little to do, in and of itself, with the duration of the time from sowing to ripening, but that this depends principally on the sunshine, so that at northern latitudes the wheat ripens best in localities that have the least cloudiness or the sunniest exposure. On the other hand, the temperature of the air does appear to materially affect the chemical constitution of the grain, since the northern crops are richer in hydrocarbons, and the proportion and quality of the starchy principle increases and the nitrogenous compounds diminish as the locality approaches the equator.

The acclimatization of plants is accompanied by notable changes in their nature; frequently the leaves increase in size relatively to the rest of the plant, and their colors are more pronounced, as if the plant sought to supplement the low temperature by a more complete absorption of the solar rays. A similar change as to the leaves and colors takes place in the flora of high mountains as compared with that of the plains below. The aromatic principles of plants are also developed in a remarkable manner in high latitudes. Thus the beans have a more decided flavor in Norway in proportion as we go northward, and at Alten (lat. 70° N.) the most aromatic cumin (*Cuminum cyminum*) of all Europe is cultivated.

The incident sunshine seems to be the productive climatic element in effecting the growth of plants; it furnishes the total vis viva, or

the mechanical or molecular energy, that is at the disposition of the plant, but it is also the last consideration to be studied and understood.

The temperature is the next important climatic element and that which has been most studied; the heat involved in temperature is the mechanical, molecular energy that is utilized by the vital powers of the plant.<sup>a</sup> Each plant utilizes a fraction of the molecular energy that is at its disposition, according as its sunshine, temperature, and sap are favorable to the formation of the chemical substances that it can elaborate within its cells. The remaining elements important to the production of crops are:

(a) The water that enters the root, which may be natural rain or artificial irrigation.

(b) The chemicals dissolved in the water.

(c) The soil that furnishes these chemicals.

(d) The atmosphere that furnishes nitrogen, oxygen, and carbonic-acid gas.

(e) The evaporation of moisture from the plant and soil, mostly through the influence of the wind and heat.

Of these, only the rain water, the gases in the atmosphere, and the evaporation are, properly speaking, meteorological or climatic elements not under the control of man; whereas the irrigation of the soil and its chemical constituents are largely under his control.

The quantity of water actually consumed by the plant or evaporated from its leaves and that which is daily evaporated from the soil or which drains away to other localities, and thus becomes useless to the plant, have been the subject of many experiments, some of whose results may be summarized as follows:

Thus, for example, Lawes and Gilbert, at Rothamsted, England, from experiments in vases entirely under their control, derived the following numbers, showing the weight of water evaporated relative to the weight of grain produced per unit area of ground:

Manure.	Weight of grain.	Weight of evapo- rated water.	Ratio.
	Grams.	Grams.	
None .....	9.6	7,353	768
Mineral fertilizers .....	7.2	6,438	882
Mineral and ammoniacal fertilizers .....	4.2	3,627	864

In these experiments, therefore, the ground during the wheat season consumed water equivalent to a rainfall of from 184 to 212 millimeters in order to produce a harvest of 30 hectoliters, or 80 kilograms in weight per hectare.

<sup>a</sup> Is it not in fact *the* vital power of the plant?—C. A.

Thus, again, Risler, at Calèves, in France, measured the harvest and the rainfall in an open field, having an impermeable subsoil. He measured the quantity of rainfall and the outflow through the drains, and allowed for the moisture in the soil at the beginning and end of his experiments. The result attained was that a field of winter wheat consumed 256 millimeters in depth of water from April to July. He does not give the quantity of grain that was harvested.

Marié-Davy, at Montsouris, cultivated winter wheat in twelve samples of earth of very different qualities, in 1874. The soil was enriched with compost, with results as in the first part of the following table.

In 1875 the soil was enriched with Joulie's complete fertilizer for cereals at the rate of 1,000 kilograms per hectare, with results as in the second part of the table.

*Evaporation and crops at Montsouris.*

Sample No.—	Experiment of 1874.			Experiment of 1875.		
	Evapo- ration.	Crop.	Ratio.	Evapo- ration.	Crop.	Ratio.
	Kilos.	Grams.		Kilos.	Grams.	
1 .....	380	304	984	362	304	919
2 .....	380	187	1,924	356	372	957
3 .....	348	300	1,160	345	474	728
4 .....	347	380	913	364	479	760
5 .....	340	303	1,122	356	426	837
6 .....	365	256	1,426	363	262	1,366
7 .....	344	328	1,049	366	435	841
8 .....	329	324	1,015	344	424	811
9 .....	339	312	1,086	346	387	804
10 .....	359	308	1,165	366	379	965
11 .....	346	313	1,105	346	460	738
12 .....	372	236	1,576	363	379	958
Average .....	352	303	1,140	356	407	877

We remark that in these two years the quantity of water evaporated has remained the same, but the harvest changed notably, being in both cases much superior to those of Rothamsted and Calèves. A box of earth, similar to those containing the wheat, lost by evaporation from January 26 to June 9, 1875, 114 millimeters, while a box planted with wheat lost 356 millimeters, and the Piche evaporimeter lost 302 millimeters. Similarly, in 1876, from the 22d of February to the 5th of July, the soil covered with winter wheat lost 426 millimeters, but the naked soil 163 millimeters and the Piche 465 millimeters. However, in this connection it must be noted that while the boxes containing naked soil received only the natural rainfall, those containing the growing plants received weekly the water that they

had lost by evaporation the preceding week. These latter, therefore, show us the maximum effect that water can have on vegetation in the climate of Paris. The proportion of water that is consumed is exaggerated, but the crop increases at the same time, but less rapidly than the consumption of water. We may, therefore, say that to a certain extent, water can with the aid of the sunshine supplement the fertilizers, although we can not say that a deficiency of fertilizer is a good thing.

In general, all the observations recorded in France, Switzerland, and England show that the total annual evaporation from cultivated soils is 70 to 80 per cent of the total annual rainfall. A large part of the rain falls in the autumn and winter when vegetation has ceased. The rains of these seasons partly filter into the earth and feed the subterranean springs, but they must first return to the soil its own water supply. Now the more the soil is impoverished by cutting the crops the more it will take up of the autumn rains and the less will be received by the subterranean water beds. It is then easy to understand that in cultivated lands the mean flow in the water courses diminishes in proportion to the progress of the cultivation. It seems certain that in France, and especially in the central portions, the grains do not find in the soil all the water that they could profitably use to the advantage of the crop and that irrigation would be advantageous in these and many other crops wherever there is a good soil and an abundance of sunshine.

Notwithstanding this necessity for water, the rainy years are frequently bad for cereals. Rainy summers are deficient in light and dry summers have too much. It is the relative distribution of heat, sunshine, and moisture from day to day throughout the whole season that is important.

From a meteorological point of view we should say that from the sowing to the formation of the embryo grain sunlight is indispensable, but from the formation to the maturity it is far less important.

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In his *Annuaire* for 1878 (p. 468) Marié-Davy gives a summary of the meteorological data, month by month, for several years, as a sample of what may be done by way of explaining the general relations between meteorology, as hitherto pursued, and the crops of the agriculturist. He says:

Meteorology, as seen from the agricultural point of view, has for its ultimate object to enable the farmer to anticipate the future of his current crop. This explains why we think it necessary to study the influence that each of the meteorological elements has on the progress of the development of the plants in the successive phases

of their growth. The tables of statistics of the climate and the crops, or the corresponding graphic diagrams, allow us to take exact account of the features of the past years and to approximately compare these characteristics with the agricultural features of the current year. Let us compare among themselves the five crops for the years from 1873 to 1877. Of these five years, 1873 gave a poor crop. On the contrary, 1874 gave a very good crop, both as to quantity and quality. The crop of 1875 attained an average as to quantity, but the quality of the grain was below the average. Notwithstanding the great irregularities of 1876 it gave us a good average as to quantity and excellent grain as to quality. In 1877, notwithstanding a great development of straw or stalks, the crop of grain was below the average as to quantity and quality; therefore, as regards their crops of grain, these years can be classed in the following decreasing order: 1874, 1876, 1875, 1877, 1873.

We will compare these harvests with the following meteorological tables for these years, as based on observations at Montsouris:

#### MONTHLY RAINFALL.

Month.	1872-73.	1873-74.	1874-75.	1875-76.	1876-77.
	<i>mm.</i>	<i>mm.</i>	<i>mm.</i>	<i>mm.</i>	<i>mm.</i>
October .....	66.9	65.2	51.0	76.9	29.2
November .....	128.1	36.5	44.2	75.4	51.0
December .....	84.6	6.0	81.8	22.4	34.8
January .....	87.3	23.1	63.2	9.1	42.2
February .....	59.1	17.5	10.9	57.8	42.9
March .....	40.4	11.4	8.6	62.7	70.5
April .....	44.5	16.1	10.1	24.3	55.9
May .....	45.2	36.6	24.6	14.3	69.5
June .....	137.9	47.8	82.0	70.6	66.7
July .....	38.8	54.5	82.1	24.6	57.7
August .....	42.7	23.1	73.7	72.3	36.7
September .....	53.6	65.1	82.8	65.3	50.1

#### MONTHLY EVAPORATIONS, AS MEASURED BY THE PICHE EVAPORIMETER.

	<i>mm.</i>	<i>mm.</i>	<i>mm.</i>	<i>mm.</i>	<i>mm.</i>
October .....	58.2	52.1	47.1	26.8	39.3
November .....	55.4	52.9	34.1	40.8	33.1
December .....	48.3	22.4	32.0	11.3	58.9
January .....		36.8	34.0	8.0	53.3
February .....		50.5	25.0	31.5	40.5
March .....	85.5	80.6	84.3	63.3	46.5
April .....	110.5	99.0	135.0	107.2	90.5
May .....	121.7	110.0	115.0	147.5	90.8
June .....	97.4	142.8	92.3	115.8	120.7
July .....	121.7	149.8	81.5	144.2	99.2
August .....	129.7	130.6	84.7	123.7	96.8
September .....	72.4	78.3	65.6	44.2	63.0

## DEGREES OF HEAT OR MONTHLY SUMS OF THE MEAN DAILY TEMPERATURES.

Month.	1872-73.	1873-74.	1874-75.	1875-76.	1876-77.
	°C.	°C.	°C.	°C.	°C.
October .....	326	350	300	291	406
November .....	258	216	180	186	213
December .....	202	99	22	71	220
January .....	152	146	167	3	198
February .....	62	120	48	122	196
March .....	254	223	174	205	183
April .....	267	312	312	301	303
May .....	375	366	437	355	357
June .....	510	528	528	500	594
July .....	628	637	552	634	570
August .....	601	561	606	606	583
September .....	435	507	534	453	390

## DEGREES OF LIGHT OR MONTHLY SUMS OF THE MEAN DAILY ACTINOMETRIC DEGREES.

	° Actin.	° Actin.	° Actin.	° Actin.	° Actin.
October .....	552	598	738	604	583
November .....	276	403	414	372	195
December .....	332	232	285	267	233
January .....	440	397	363	406	363
February .....	353	490	423	453	353
March .....	791	871	766	800	763
April .....	909	1,152	1,248	1,191	1,050
May .....	1,401	1,442	1,453	1,482	1,134
June .....	1,398	1,566	1,359	1,458	1,622
July .....	1,702	1,590	1,428	1,569	1,439
August .....	1,376	1,311	1,172	1,243	1,254
September .....	930	945	1,041	900	898

Our summaries are divided into three periods. The first, October to February, corresponds to the sowing and the winter season; the second, March to July, corresponds to the vegetation of the cereals; the third, May to September, corresponds to vegetation of the vine. In these summaries the years are rearranged in the order of the decreasing value of the grain harvest.

*Summary from October to February.*

	1873-74.	1875-76.	1874-75.	1876-77.	1872-73.
Rainfall .....	148	242	251	200	376
Evaporation .....	215	118	172	225	-----
Degrees of heat .....	981	673	777	1,233	1,000
Degrees of light .....	2,187	2,102	2,226	1,727	1,953

In the first period, or the winter, the climatological facts have very little apparent bearing on the crops. The sowing period may have been more or less difficult, but very pronounced anomalies in the climate must occur in order to compromise the harvest in an irremediable manner. The year 1872-73 is the only one that presents a fact of



this latter kind. The excessive rains of autumn drowned the wheat and produced disastrous inundations. Up to that time we perceived the influence of the light, which strengthens the young shoots and gives them a real progress, but which may be promptly effaced by the subsequent bad weather.

*Summary from March to July.*

	1873-74.	1875-76.	1874-75.	1876-77.	1872-73.
Rainfall.....	168	197	207	320	307
Evaporation.....	582	558	508	448	537
Degrees of heat.....	2,096	1,965	2,053	2,007	2,029
Degrees of light.....	6,621	6,450	6,249	6,008	6,201

In the second period the light is the element which appears to be of the least importance. Its variations do not correspond to the value of harvest attributed to each year. It is not the same with the rainfall, which increases regularly in proportion as the harvest becomes less favorable. The two last years, 1877 and 1873, differ little from each other in general characteristics.

Experience shows that we may water grain planted in pots or in free earth every day and only increase the quantity and quality of their product instead of diminishing them. It is not, therefore, that rain water in itself is injurious—far from it; but rainfall brings with it cloudy weather, which diminishes the light. We see in fact that the sum of the actinometric degrees decreases regularly in proportion to the increase in the value of the crop year, except in the case of the last year, 1873, which only descended to this rank in consequence of the meteorological accidents of the autumn. In reality 1873 would have been a more favorable year for the crops than 1877 if the autumn had not been so exceptionally unfavorable. The crop of 1877 only recovered its value, because of the abundance of the wheat stalks. Thus we see that it is in vain that the season be favorable as regards weather if the heads of the grain are scarce.

*Résumés from May to September.*

	1873-74.	1875-76.	1874-75.	1876-77.	1872-73.
Rainfall.....	227	247	295	281	318
Evaporation.....	612	575	439	468	543
Degrees of heat.....	2,629	2,548	2,709	2,494	2,544
Degrees of light.....	6,854	6,602	6,448	6,347	6,807

This third period relates to the wine crop. During this period, as in the others, heat seems to play only a very secondary part for the same country. There would not be the same difference in the nature of the product from one country to another. On the contrary, the quantity of light decreases regularly from the first or best crop to the year before the last or poorest crop. The last year, on the other hand, which was so bad at the beginning, recovered in a most extraordinary manner at the end, and as regards the quality of the

wine this year should have had a great similarity with 1874. Nevertheless, the wine of 1873 was not of very good quality, which can perhaps be attributed to a too prolonged growth of the vine stems, caused by the humidity of the soil. If in general a good wheat year corresponds with a good wine year this rule is far from invariable. In regard to quality the vintage depends but too often on the late spring frosts.

The extremely important part played by light in agriculture makes us regret that the actinometer should still be so little known. It perfectly replaces the thermometer for agricultural purposes, but the thermometer can not take its place.

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In his *Annuaire* for 1882 Marié-Davy gives the following study of the development of cereals, wine, and other crops:

*Cereals.*—The cereals offer a great number of varieties, and this number increases annually, but often the differences that we see between them are due to certain influences of the soil and climate which disappear by change of locality. However, there are some varieties whose qualities have been fixed by long-continued cultivation in the ordinary way or by long-continued selection, and which present decided advantages for the specific climates.

The varieties brought from the south are more sensitive to cold than those from the north, and can not be propagated without special precautions in higher latitudes or at greater altitudes than belong to the localities where these varieties were gradually developed. The varieties brought from the north are generally more precocious and suffer more from dryness. The expressions “early” or “late” have reference to their behavior in the new locality. The grain brought from the south comes to maturity at a later date than that raised in the north.

*Influence of heat and light on development of wheat.*—We shall divide the development of wheat into four phases, whose dividing epochs are the processes of (1) sowing and germination, (2) heading out, (3) flowering, and (4) ripening. According to Gasparin the germination of wheat begins when together with the necessary moisture it also enjoys a temperature in excess of  $5^{\circ}$  C., and it sprouts when it has received a sum total of effective mean daily temperatures (above  $5^{\circ}$  C.) equal to  $84^{\circ}$  C. Its sprouts shoot above the soil a few days later. Some wheat sown by Marié-Davy April 23, 1880, was up on the 4th of May, the sum of the mean temperatures being  $96^{\circ}$ , so that the germinating sprout had taken about two days to grow from the seed to the surface. In the following table columns 2, 3, 4, and 5 show the duration in days of the period required for the germination of wheat supposed to be sown at Montsouris in the different years on four different dates—*a*, *b*, *c*, *d*—as stated at the heads of the columns. These durations are calculated to the nearest whole days, on the

assumption that the sum of the mean daily temperatures in the shade must be 84° C.

[Date of sowing: *a*, October 1; *b*, October 15; *c*, November 1; *d*, November 15. Average date of germination: *a*, October 7; *b*, October 22; *c*, November 14; *d*, December 18. Average date of heading: *a*, February 8; *b*, March 4; *c*, March 3; *d*, February 26.]

Year.	Duration of germinating stage.				Duration of heading stage.			
	<i>a.</i>	<i>b.</i>	<i>c.</i>	<i>d.</i>	<i>a.</i>	<i>b.</i>	<i>c.</i>	<i>d.</i>
	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1873 .....	5	6	12	13	111	159	142	142
1874 .....	7	6	9	23	151	166	163	143
1875 .....	6	7	9	40	151	165	148	118
1876 .....	5	7	13	12	59	87	98	113
1877 .....	9	10	8	17	128	130	149	137
1878 .....	6	6	28	45	151	179	151	128
1879 .....	7	9	11	94	155	158	152	57
1880 .....	6	9	16	28	86	133	125	87
Average duration .....	6.4	7.5	13.0	33.4	124	147	140	116

Counting from the date when the mean daily temperature is 5° C. and the wheat begins to sprout to the date when the wheat begins to head, Gasparin adopts 430° C. as the sum of the mean daily shade temperatures. Marié-Davy finds from the date of actual sowing of the seed to the date of heading out a sum of 555° C. after rejecting all daily mean temperatures that are below 6° C. according to the rule of Hervé Mangon. He also finds 639° C. for the sum total of temperatures between the dates of germination and heading out after rejecting all days below 6° C. On this last hypothesis are calculated the duration of the heading stage and the mean dates of heading for the respective years as given in the columns 6 to 9 of this table. These computed dates of heading out show that the sowing of wheat on October 15 or November 1 or 15 brings it to a head at the end of February or beginning of March, but when the sowing occurs on October 1 it is brought to a head so much earlier in February as to expose it to great chance of injury by the frost; for although the grasses and the green wheat plant resist the action of frost, yet the embryo seed in the ear or head does not do so, and if once destroyed by frost will not be replaced unless the soil is very fertile.

The third epoch, or the flowering of the wheat, takes place in France, according to Gasparin, when the mean temperature has risen to 16° C. or when the sum total of daily shade temperatures has amounted to 813° C., counting from the beginning of vegetation in the spring or from the date when the mean daily temperatures is 5° C. in the shade. This figure relates, of course, to an average of many years, and the individual years may vary very considerably. Marié-Davy, as before, adopts the views of Hervé Mangon as to

rejecting all mean daily temperatures below 6° C., and thus finds 1,496° as the mean value of the sum of temperatures from the date of sowing to that of flowering. The similar sum from the date of heading to flowering is 860°, or 1,496° less 639°.

The fourth epoch, or the ripening of the wheat, occurs when the sum total of the mean daily shade temperatures since the date of flowering, rejecting all below 6° C., amounts to 815° C., and in the climate of Paris this occurs about forty-five or forty-six days after the date of flowering. The range of uncertainty in this last interval is only four or five days, owing largely to the uniformity of the climate at this season. It is the best defined of all the periods and so well ascertained that, knowing any actual date of flowering we can safely predict the date of ripening. In proportion as we approach the latter date the process of ripening seems to concentrate itself more and more within the wheat; water and sunlight become less and less important; rain becomes a source of uneasiness as to the harvest, and the intensity of sunshine has only an indirect influence on the quality and quantity of the grain. The influence of sunlight during the first phase or germination is negligible and probably nothing; it is a maximum at the beginning of the fourth phase, but diminishes rapidly as the fourth phase progresses and in proportion as the wheat becomes more yellow. We shall therefore consider the amount of sunshine, or more properly the total radiation from sun and sky, during the first thirty days after flowering and neglect its amount during the remainder of the period up to maturity.

The following table shows the amount of radiation, as expressed by Marié-Davy in actinometric degrees or percentages and computed from actual observations of his actinometer at Montsouris for the various stages of growth, viz, the second or heading stage from germination to heading, the third or flowering stage from heading to flowering, and fourth for the first thirty days of the fourth or ripening stage immediately following the flowering:

Year of sowing.	Total radiation received during heading stage.				Total radiation received during flowering stage.				Total radiation received during 30 days of ripening stage.			
	a.	b.	c.	d.	a.	b.	c.	d.	a.	b.	c.	d.
1873 .....	842	1,332	1,755	1,848	3,205	2,979	2,870	2,954	1,176	1,608	1,548	1,581
1874 .....	908	1,191	1,663	1,938	3,031	2,933	2,620	2,482	1,403	1,220	1,171	1,194
1875 .....	904	1,009	1,161	1,247	3,214	3,169	3,169	2,821	1,419	1,504	1,526	1,558
1876 .....	652	698	646	811								
1877 .....	733	739	977	1,255	2,086	2,302	2,282	2,208	1,103	1,199	1,399	1,450
1878 .....	800	1,382	1,476	1,743	2,749	2,634	2,630	2,506	1,320	1,496	1,131	1,184
1879 .....	840	1,251	1,582	1,600	3,095	2,580	2,658	2,607	1,076	1,092	1,321	1,362
1880 .....	1,000	1,578	1,924	1,991	3,519	3,106	2,849	2,865	1,391	1,433	1,433	1,486
Average of 6 years....	857	1,117	1,497	1,653	2,977	2,808	2,723	2,629	1,268	1,363	1,360	1,363

If we sum up the second, third, and fourth series of figures we finally obtain the sum total of the effective radiation received during the whole interval from germination to ripening, as given in the following table:

Year.	Total radiation received from germination to ripening.				Average for Oct. 22.	Relative value of actual crop.
	a.	b.	c.	d.		
1873 .....	5,223	5,919	6,173	6,383	5,924	25.2
1874 .....	5,342	5,344	5,454	5,614	5,438	19.0
1875 .....	5,537	5,682	5,856	5,626	5,676	26.5
1876 .....						22.5
1877 .....	3,932	4,240	4,658	4,913	4,436	15.2
1878 .....	4,869	5,512	5,237	5,433	5,263	11.1
1879 .....	5,011	4,923	5,561	5,509	5,266	-----
1880 .....	5,910	6,117	6,206	6,345	6,145	-----
Average of 6 years.....	5,102	5,288	5,550	5,645	5,396	-----

The relative value of the wheat crops, as observed at two stations, is given in the last column of the preceding table, and the comparison of the figures shows that a deficiency of sunshine has a decided effect in diminishing the relative value of the crop; but the converse is not true, for we may have an excess of sunshine and still get poor crops, owing to a deficiency of rain or irrigating water. In fact, the preceding study only shows the nature of the influence of the solar radiation; the exact quantitative effect on the amount of the crop must vary with the irrigation or rainfall, with the fertilizers applied to the soil, and with the peculiarities of the seed.

As to the rainfall, it was in the preceding cases distributed as shown in the following table:

Year of sowing.	Rainfall during stages.				Total sunshine from germination to ripening.
	Germinating.	Heading.	Flowering.	Ripening.	
1873.....	1.19	0.75	0.78	1.72	5,924
1875.....	2.97	1.38	0.99	1.44	5,676
1878.....	1.84	1.60	1.65	1.94	5,263

From these figures we conclude that the excess of rain in the wheat season of 1878-79, which would have been advantageous with a clear sky, as in Egypt,<sup>a</sup> was at Paris accompanied by too little sunshine, and therefore the crop suffered. For a given quantity of sunshine a certain quantity of water is best for the crop; if the sunshine is diminished the plant can not use so much water, and that must be correspondingly diminished.

<sup>a</sup> Or as in the case of irrigation in the arid portions of the United States.—C. A.

The influence of the date of sowing and its relation to sunshine and frost is fully shown in the table for Montsouris, which gives the sum total of actinometric degrees from the time of germination to maturity for seeds sown on successive weeks in 1879, 1880, and 1881, and harvested in 1880, 1881, and 1882:

Date of sowing.	Total sun- shine from germination to ripening (actinomet- ric degrees).	Date of sowing.	Total sun- shine from germination to ripening (actinomet- ric degrees).
1879.		1880.	
October 1.....	5,011	November 24.....	6,393
October 8.....	5,144	December 1.....	6,461
October 15.....	5,074	December 8.....	6,529
October 22.....	5,574	December 15.....	6,611
November 1.....	5,561	December 22 <sup>e</sup> .....	6,504
November 8.....	5,596	December 29 <sup>e</sup> .....	6,245
November 15.....	5,569		
November 22.....		1881.	
		January 5.....	
1880.	(a)	January 12.....	(f)
February 8.....		January 19.....	
February 15.....	5,622	January 26.....	6,245
February 23.....	5,597	February 2.....	6,018
March 1.....	5,581	February 9.....	6,047
	(b)	February 16.....	6,043
September 29 <sup>c</sup> .....	5,910	February 23.....	6,037
October 6 <sup>c</sup> .....	6,052	March 2.....	6,037
October 13.....	6,117	March 9.....	5,571
October 20 <sup>d</sup> .....	6,091	March 16.....	5,236
October 27 <sup>d</sup> .....	6,118	March 23.....	5,271
November 8 <sup>d</sup> .....	6,206	March 30.....	5,215
November 10.....	6,204	April 6.....	5,144
November 17.....	6,343		

<sup>a</sup> Frozen soil prevented sowing.

<sup>b</sup> No sowing during this interval.

<sup>c</sup> See note 1 in text.

<sup>d</sup> See note 2 in text.

<sup>e</sup> See note 3 in text.

<sup>f</sup> Frozen ground prevented sowing.

Among other conclusions that may be drawn from these figures are the following, most of which are also given by Marié-Davy:

1. The season 1880–81 was characterized by much sunshine and little rain, which hastened the ripening, but delayed the flow of sap, and therefore of nourishment to the grain, so that the crop was rather poor.

2. For the crops of fall wheat the sunshine increased more and more as the seed was sown later from September, 1880, even to the end of December; then it began to diminish, and for the spring wheat, sown in March, 1881, it was too small.

3. By considering other weather records it is evident that the freezing of the ground in January, 1881, not only prevented the sowing of the seed, as noted in our table, but prevented the germination of the seeds sown on December 22 and 29, 1880, which would otherwise have sprouted on February 4 and 19, 1881, respectively.



4. The wheat sown September 29 and October 6, 1880, which headed out December 30 and February 19, was injured as to the heads by the subsequent frost.

5. The seeds sown October 20, 27, and November 3, 1880, flowered between the 4th and 8th of June, 1881, but at this time there was experienced at Paris a spell of very cold weather, the minimum daily temperature being  $3.1^{\circ}$  C., and even white frosts were reported, so that wheat which was then in flower was badly injured.

6. In general, the dates November 10, 1880, to December 15, 1880, are those indicated as most favorable for sowing wheat in that year, and the crop of 1881 may be predicted as likely to be small, but of excellent quality.

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*The grape and wine crop.*—In a short study on the relation between the vine and the weather, Marié-Davy (1882, p. 290) states that, in general, the annuals, such as the cereals, concentrate all their energy in the formation of the ear and the seed or grain. Their work is then finished and they die. The next year's crop of these annuals is largely under the control of the husbandman, who can obtain seed from more favored regions if his own crop was inferior.

On the other hand, the work of the vine, like all perennials, is not merely to ripen its fruit and seed, but to preserve its own individual self for usefulness in future years. Therefore it elaborates out of its own sap not merely leaves and fruit and seed, but a store of woody fiber. Corresponding to this more complex system of growth the relations of the perennials to the climate are apparently more complex than the relations of the annuals, and, it may also be added, the range of geographical distribution, whether by nature or by cultivation, is more restricted.

Our studies will be confined to the data furnished by the observations at Epernay (1873–1881), to which Marié-Davy adds other data computed from the observations made at Montsouris, in which latter computation certain laws of growth of the vine as established by Gasparin were adopted.

In the neighborhood of Paris the leaf buds of the vine burst open in May when the mean daily temperature has permanently passed above  $11^{\circ}$  or  $12^{\circ}$  C. Assuming that the mean of twenty days, as observed at Montsouris, will give this date (which was unfortunately not observed at Epernay), we obtain the figures in the first three columns of the following table. In some of these years the early leaf buds were undoubtedly killed by nocturnal frosts, but they were soon replaced by other buds, and the dates here given must be adopted in the absence of actual observations, especially when we remember that the quantity and quality of the final crop of grapes depend not only



on the meteorological conditions, but, equally or more, on the condition of the woody fiber of the stock and stems. Similarly the date of flowering is calculated by assuming, with Gasparin, that the sum total of the mean daily temperatures in the shade must be  $466^{\circ}$  C., counting from the date of leafing. This number is more especially applicable to the vineyards of Champagne and Burgundy, and is not necessarily strictly applicable to Epernay or to the vineyards of the south of France. The fifth and subsequent columns of the table give the mean climatic conditions for a period of sixteen days, in the middle of which is the calculated date of flowering. There appears to be no simple relation between this latter data and the resulting wine crop, nor has the crop any apparent relation with the total sky radiation during this period. In fact we may conclude that up to the time of flowering the energy of the vine has been devoted to building up its own structure as a preparation for the work that is to come. The development of the grape does not depend upon nitrogenous particles stored away in the vine, but on the power to elaborate the sap which is to become the juice of the grape, and that power depends upon the leaf surface, the roots, and the stock during the first stages of the growth of the grape, but eventually upon changes that go on within the grape itself.

These facts are brought out by the study of the conditions prevailing during the last stages, viz, from flowering to maturity :

Calculated date of leafing.	During 20 days.		Calculated date of flowering.	During 16 days.		
	Average temperature.	Total rainfall.		Average temperature.	Average radiation.	Total rainfall.
	$^{\circ}$ C.	mm.		$^{\circ}$ C.	$^{\circ}$ Actin.	mm.
May 21, 1873.....	12.1	25.3	June 22 .....	18.7	46.1	88.1
May 20, 1874.....	13.2	20.5	June 18 .....	16.8	41.5	26.8
May 9, 1875.....	16.0	25.5	June 6 .....	19.0	55.2	38.3
May 28, 1876.....	14.2	3.0	June 25 .....	19.4	49.0	52.3
May 13, 1877.....	11.5	56.8	June 12 .....	20.9	51.6	18.3
May 16, 1878.....	14.1	51.7	June 16 .....	16.4	40.3	55.1
May 21, 1879.....	12.6	35.9	June 22 .....	16.6	43.0	25.7
May 16, 1880.....	14.0	0.0	June 16 .....	16.2	37.6	45.5
May 21, 1881.....	14.6	29.0	June 8 .....	14.9	48.7	15.2
Average May 18 ...	13.6	27.5	Average June 16 ..	17.7	45.9	40.6

According to Gasparin the grape reaches its maturity when it has received a sum total of mean daily shade temperatures of  $1,926^{\circ}$  C., counting from the date of flowering, but the grape ceases to be nourished or to ripen when the mean daily temperature falls below  $12.5^{\circ}$ . If, now, we ascertain the date of maturity by summing up the daily temperatures, as required by Gasparin's rule, we obtain the results given in the first column of the following table. If we

take the mean values for the twenty days previous to the date of maturity we obtain the data in the second, third, and fourth columns, and we notice that although in the warmer seasons there may be a great variety in the value of the crop, yet in the cold seasons, 1877 and 1879, when the mean temperatures fell below the limit ( $12.5^{\circ}$ ) required for ripening, the crop was very poor or failed altogether. If now the total radiation from sun and sky is computed according to Marié-Davy's method for the period between leafing and flowering and again from flowering to maturity we obtain the figures in the columns five, six, and seven. Here we see, as before, that the variation during the flowering period was of little importance, whereas that during the ripening period has a direct relation to the character of the wine crop, such that in general the larger the total radiation the better the crop, provided the temperature of the air has not fallen too low.

Calculated dates of ripening.	During previous 20 days.			Total radiation by stages.			General character of—		
	Mean daily temperature.	Mean daily radiation.	Total rainfall.	Leafing to flowering.	Flowering to ripening.	Sum.	Juice.		Wine crop.
							Sugar.	Acid.	
	° C.	° Actin.	mm.	° Actin.	° Actin.	° Actin.			
October 7, 1873.....	16.1	30.2	20.3	1,278	4,590	5,868	162	8.2	Excellent.
September 25, 1874.....	16.0	27.6	28.8	1,343	4,544	5,887	179	6.1	Finest.
September 21, 1875.....	17.4	40.6	5.9	1,306	4,322	5,728	181	5.4	Good.
October 7, 1876.....	16.2	27.7	16.7	1,222	4,205	5,427	174	6.8	
October 2, 1877.....	11.9	30.4	8.2	1,280	4,603	5,883	186	8.7	Very poor.
October 2, 1878.....	13.3	25.5	23.8	1,238	4,165	5,403	181	6.7	Good.
October 15, 1879.....	11.5	26.1	6.3	1,355	4,033	5,388	154	9.5	Very poor.
September 29, 1880.....	15.2	27.8	25.0	1,305	3,966	5,301	188	6.4	
September 26, 1881.....	15.1	24.2	81.2	1,575	4,262	5,837	180	6.1	Excellent.
Average October 2.....	14.7	28.9	24.0	1,322	4,302	5,624	176	7.1	

In general, Marié-Davy concludes that the number of grapes to the bunch and the number of bunches to the vine do not seem to have any clear relation to meteorological conditions, except in the case of spring frosts, which can destroy a crop. Besides the conditions as to pruning the vine and dressing the soil, the number of grapes that have set (on which principally depends the quantity of the crop that will be produced) is a result primarily of the meteorological conditions during the previous year and of the state of preparation of the woody stock. On the contrary the final size of the grapes and the quality of the juice depends on the meteorological conditions of the crop year and those that accompany the flowering and succeed it up to the time of maturity. A final sum total of radiation is not sufficient; it is necessary to take account of its distribution with reference to the

phenological periods and of other accompanying circumstances. Thus in 1877, with a low mean temperature and a high radiation during maturity, and in 1879, with a low temperature and a low radiation during the last phase, both alike gave a poor crop, but the sunshine of 1877 was able to make a large quantity of sugar as compared with the small quantity of sugar in 1879.

*Sugar beets.*—Marié-Davy (1882) and Pagnoul (1879) give the data of a research into the relation of climate to the development of sugar beet as cultivated at Arras, the agricultural station of the Department of Pas de Calais. The following table gives the results of meteorological observations and chemical analyses of sample beets taken up every ten days during the season. The beets were sown April 5, 1879, averaging six plants to the square meter. They were of a poor variety, but of the kind ordinarily planted in that section; they were of a rosy color, and were planted a great distance apart in order that they might grow more rapidly.

Decade ending 1879.	During the decade.				At end of decade.				
	Total rain.	Total heat (sum of mean daily shade temperatures).	Total sunshine (daily average of clear sky).	Total radiation (sum of daily actinometric degrees at Mont-souris).	Average weight of—		Average density of juice.	Weight of sugar per 100 beets.	Weight of sugar per hectare.
					Root.	Leaves.			
	mm.	° C.	Per cent.	° Actin.	Kilos.	Kilos.	Beau-mé.	Kilos.	Kilos.
June 11.....	83	156	41	393	1	8	2.9	3.03	2
June 21.....	37	162	30	479	7	41	2.8	2.18	9
July 1.....	18	159	31	444	31	110	3.3	5.18	96
July 11.....	56	138	16	399	105	222	3.5	5.38	339
July 21.....	59	165	26	320	220	333	3.2	5.88	776
July 31.....	26	158	28	378	346	462	3.9	6.85	1,422
August 10.....	8	179	31	416	486	452	4.0	6.33	1,848
August 20.....	24	182	43	361	666	433	4.2	7.69	3,073
August 30.....	18	177	36	373	778	335	4.1	7.57	3,534
September 9.....	4	159	56	385	878	312	4.4	8.20	4,320
September 19.....	27	165	34	326	1,040	200	4.3	7.46	4,655
September 29.....	10	131	49	251	1,048	126	4.1	7.46	4,691
October 9.....	5	129	25	334	1,048	194	4.4	8.06	5,068
October 19.....	18	95	12	161	1,056	98	4.1	7.46	4,727
October 29.....	23	87	26	144	1,050	128	4.5	7.94	5,002

The influence of sunshine is to be found by studying the fourth column of the sum total of daily average cloudiness at Arras, as resulting from twelve daily observations of the amount of cloudiness. The clearness of the sky, as given in the fourth column in percentages, is

the complement of the cloudiness and represents the relative duration of sunshine, but owing to the varying altitude of the sun can by itself alone give no idea of the intensity of the radiation received by the plant. To obtain this last item and as no actinometric observations were made at Arras I give in the fifth column the results of observations at Montsouris, expressed in actinometric degrees.

The beets are reported to have sprouted very late and very unequally; this was due not to dryness, since the rain during March and April was in excess of its normal value, but was directly traceable to the low temperature, which was especially low in April.

The study of the development of sugar, week by week, as given in the last two columns of the above table shows that after September 9 the sugar crop increased slowly, became stationary, and then fluctuated very much as the weight of the leaves fluctuated. The rainfall had at that time become light and the development of the beet seemed to depend mostly on the temperature, so that it may be concluded that the beet ceases to increase in its quantity of sugar after the mean daily temperature falls below  $13.1^{\circ}$  C., and that there is no probable advantage in leaving the beets in the soil after that date, which in this case is September 29, 1879.

Marié-Davy points out that the actual increase per decade of the weight of the roots coincides with the increase of the rainfall and the temperature, but the proportion of sugar increases with the degree of radiation or total sunshine; the sunshine precedes the formation of sugar, since its action is slow and indirect, being through the assimilation that takes place within the leaves. It is therefore not an excess of water, but a deficiency of light and heat that causes rainy autumns and summers to give poor crops of sugar. Therefore, if during dry, clear, warm summers having large radiation, one could irrigate the fields properly one would realize the best conditions for a good crop. Therefore, every ray of sunshine that strikes the ground instead of the leaf is a loss to the formation of sugar and by helping to evaporate the moisture of the soil it also causes further great loss of sap to the plant. These conclusions agree with other experiments made by Pagnoul, who raised beets both in darkness and under a transparent bell glass, and again in the free air, and found the amount of sugar to increase with the strength of the sunshine.

The following table gives a general survey of the beet crops in Pas de Calais and the corresponding climatic data at Montsouris, which is about 90 miles south of Arras. The numbers given in the columns for quantity and quality of the crops are the estimates obtained from many planters and are recorded on the following scale: 1, very small

or very bad; 2, small or bad; 3, passable or mediocre; 4, fairly good; 5, good; 6, very good.

Year.	Dates when mean temperature of air thermometer in shade—		Duration beet root season.	During the season.			General character of sugar crop in Pas de Calais.		
	Rises above 9° C.	Falls below 13° C.		Sum of mean daily air temperature.	Sum of mean daily radiation.	Total rainfall.	Quantity.	Quality.	Density of juice.
			Weeks.	° C.	° Actin.	mm.			Beau-mé.
1873.....	Mar. 23	Oct. 12	29	3,079	.....	303	4	5	5.8
1874.....	Mar. 16	Oct. 19	31	3,889	8,963	264	5	3	4.6
1875.....	Mar. 30	Oct. 5	27	3,172	7,900	313	6	3	4.2
1876.....	Mar. 23	Oct. 19	30	3,003	8,539	299	1	1	3.9
1877.....	do	Sept. 21	26	2,786	7,326	344	4	6	5.5
1878.....	Apr. 6	do	24	2,791	6,552	347	5	3	4.7
1879.....	Apr. 20	do	22	2,359	5,815	278	1	3	4.4
1880.....	Mar. 2	Oct. 11	32	3,132	8,410	280	.....	.....	.....
1881.....	Apr. 6	Sept. 28	25	2,520	6,300	340	.....	.....	.....
Average .....	Mar. 26	Oct. 4	27	2,915	7,484	306	.....	.....	.....

The climatic data given in the above table as directly applicable to the seasons of growth of the beet root illustrate what should be given for any similar study of development of any crop. But it is commonly the case that the dates of the various phenological epochs are not exactly given, and that we have to rely upon general tables of general climatic conditions month by month, such as are recommended by the International Meteorological Congress of Vienna and by that of Rome. Therefore, for the sake of comparison with other climates whose data are given on the so-called international forms, I give in the following table a part of Pagnoul's tables of average temperature Centigrade and rainfall in millimeters as observed at Arras:

Year.	Mean daily shade temperature.							Total monthly rainfall.						
	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.
1873.....	8.6	11.0	16.7	19.1	18.2	13.5	9.9	48.6	45.5	63.3	26.2	40.3	33.5	56.1
1874.....	11.0	11.4	16.6	20.1	17.0	15.5	11.0	20.7	32.9	25.7	16.0	34.2	92.3	47.2
1875.....	9.6	14.7	16.7	17.4	19.1	16.6	9.0	8.0	30.7	32.0	63.7	62.0	74.5	61.6
1876.....	9.3	14.8	16.7	19.6	19.3	13.9	12.1	41.3	15.3	32.0	23.8	87.3	87.0	24.5
1877.....	8.8	11.3	19.1	17.8	17.7	12.3	9.7	45.0	38.2	23.0	61.2	96.5	50.3	48.5
1878.....	16.3	14.2	17.2	18.0	18.6	14.9	10.6	53.7	38.4	60.6	46.7	36.6	42.9	37.3
1879.....	7.6	10.6	15.9	15.5	17.6	15.1	9.8	48.4	51.7	138.6	142.0	50.5	39.5	45.4

The preceding study gives a first idea as to the relation between climate and the development of the leaves, the roots, and the sugar, and offers a first step toward determining how suitable for the beet-sugar industry any climate may be, and especially does it suggest to

the planter how he may early in August begin to safely predict from week to week what his probable crop will be early in October. Thus, table on page 259 shows, by the samples taken August 20, that there were then in the beets 3,073 kilograms of sugar per hectare, whereas on October 9 there was 5,068, or five-thirds of that present on August 20. This factor, five-thirds = 1.67, is, therefore, that by which the figures of August 20 are to be multiplied in order to obtain those of October 9. The following table gives similar factors for the successive decades for the crop of 1879, and when a succession of years has been thus treated we shall know something of the accuracy with which the harvest crop can be predicted. The regularity with which these numbers run shows that after the 1st of September the error of prediction can only be a small per cent.

Date of sampling (1879).	Crop factor for this date	Weight of sugar.
August 10.....	2.74	1,848
August 20.....	1.65	3,073
August 30.....	1.43	3,534
September 9.....	1.17	4,320
September 19.....	1.09	4,655
September 29.....	1.08	4,691
October 9.....	1.00	5,068

Pagnoul calls attention to the fact that the roots contain a considerable portion of nitrates, although the soil in which they grow had not received during this or previous years a trace of these salts. This salt could only have come into existence by the nitrification of organic nitrogenous matter, and it is well to insist upon this fact, for we can thus remove from the minds of certain persons the idea that if the beet root contains nitrates they must have been put into the soil by the cultivator. This mistake has frequently caused unhappy contests between the farmer and the sugar manufacturer.

If the beet root had at its disposal only a proper proportion of nitrates that had been formed in the soil before sowing, these salts would be rapidly absorbed; they would by their decomposition give rise to a large and prompt development of leaves, and, consequently, to an easier elaboration of sugar, and in proportion as vegetation advances we should find smaller quantities of nitrates in the beets. This fact was proven by Marié-Davy in 1878.

If on the contrary the nitrogen is furnished by a process of nitrification that is prolonged during the whole season, then the absorption of the nitrates goes on continuously and their total weight per hectare increases steadily to the end of October, as shown in these analyses for 1879.



Some further experiments by Pagnoul (1879, p. 486) on the beet as grown in darkness and in sunshine shows that the former were exceptionally rich in alkali, ash, and especially the nitrates. This is explained as above, viz: The nitrates will not decompose within the plant except under the influence of sunshine; if the plant is kept in darkness it stores up the nitrates within itself without having the power of utilizing its own nitrogen, so that the substances in the formation of which this nitrogen ought to be of assistance can not be formed.

From this one must conclude that years that are bad for the beet-sugar crop are so not only because of unfavorable temperatures and humidities but above all because of a defect in the insolation. Lively complaints have been made of the quantity of nitrates in certain harvests; now these salts that accumulate in the molasses and in the inferior products and augment the difficulty of the work occur often in beets cultivated upon a soil that has never received a trace of nitrates as a fertilizer. It is therefore not to the abuse of nitrates as a fertilizer that we ought to attribute their presence, but rather to a too cloudy sky.

We know that the neighborhood of large trees is injurious to the vegetation around them. Ordinarily we attribute this injurious influence to their roots. It would perhaps be more exact to attribute it to the shade that they cast, and the more so because it has been demonstrated by Cailletet that green light has no power to bring about the decomposition of carbonic acid.

In the *Annuaire* for 1883 Marié-Davy studies the influence of the date of sowing. In order to ascertain the best dates for sowing and trace out the various vicissitudes to which the crop is subject, whether resulting from the climate as such or from the ravages of insects or fungi, it is necessary to make a rather detailed study of the state of development of the plant under the assumption that the seeds were sown on successive dates—for instance, on a given series of successive week days. An elaborate study of this kind is given for wheat by Marié-Davy (pp. 244–285 of his *Annuaire* for 1883), from which the following tables have been extracted. In general the varieties of wheat cultivated in the south of Europe are more sensitive to cold than those of the north, but the studies of Marié-Davy for the latitude Montsouris, when paralleled by similar studies for localities in the United States, can but be of the greatest value both to the farmers and the statisticians of this country. The study of such tables will enable one to very closely predict the time of harvest, the quantity and quality of the crop, and the range of uncertainty. To this end it is, of course, understood that corresponding elaborate tables of



meteorological conditions must be accessible, samples of which I have prepared for twenty United States stations.<sup>a</sup>

If we suppose some wheat to have been sown on the 22d of September, 1871, near Paris, and if we adopt the rule established by Gasparin that the vitality of the seed is actively aroused as soon as its temperature in a moist earth exceeds 5° C., and that it germinates visibly when it has received a sum total of mean daily temperatures that is equal to 85° C., and that the sprout rises above the surface of the earth in a few days after the seventh, then we obtain six days as given in the following table for the interval from sowing to germination. A similar computation for every other date of sowing, as given in the following table, shows at a glance the effect of the temperature of the soil on this phase of plant life.

*Duration, in days, from sowing to germination of winter wheat at Montsouris, France, for the years 1872-1881.*

Date of sowing.	1871.	1872.	1873.	1874.	1875.	1876.	1877.	1878.	1879.	1880.	1881.	Germination.	
												Average duration for the years 1872-1881.	Average date.
September 22...	6	7	7	5	5	7	8	7	7	6	6	7	Sept. 29
September 29...	7	7	5	7	6	6	8	7	7	7	10	7	Oct. 6
October 6.....	8	9	7	7	9	5	8	7	8	7	8	8	Oct. 14
October 18.....	8	8	9	6	8	7	10	7	10	10	11	8	Oct. 21
October 20.....	12	8	13	10	11	11	5	7	9	22	15	11	Oct. 31
October 27.....	70	8	13	9	11	16	8	29	14	18	18	20	Nov. 16
November 3.....	72	15	15	14	8	12	8	25	16	14	7	20	Nov. 23
November 10....	77	15	17	32	8	8	14	48	98	9	10	33	Dec. 13
November 17....	70	9	12	49	41	13	12	44	93	21	10	36	Dec. 23
November 24....	63	10	25	53	42	11	25	39	89	17	26	37	Dec. 31
December 1.....	56	16	43	48	35	8	46	69	82	12	42	42	Jan. 12
December 8.....	49	16	36	42	28	22	67	62	75	11	67	41	Jan. 18
December 15....	42	12	25	35	21	12	60	55	68	13	60	35	Jan. 19
December 22....	35	11	30	28	56	14	55	48	61	43	57	38	Jan. 29
December 29....	28	19	26	21	53	9	49	42	53	44	50	34	Feb. 1

In studying the preceding table we recall that the duration of germination varies slightly with the condition of the soil and the depth of the grain below the surface; these two considerations will be perfectly allowed for if we observe directly the temperature of soil by a buried thermometer. Such observations are earnestly recommended to all agricultural experiment stations, as they are, evidently, more directly applicable to the growth of plants than any crude

<sup>a</sup> These tables are omitted in the present edition.

approximations derived from the observation of the temperature of the air only. If when the grain has sprouted the soil continues very dry, the nourishment having all been drawn from the seed, the young plant may droop and die. If, again, the frost penetrates to the seed while it is germinating, many of the seeds will perish, and the field will appear as if sparsely sown, but this latter mishap is generally repaired by nature if the soil is good and the springtime favorable, for the sowing is generally in excess and the extra heading will supply the loss of the seeds that have perished, but in poor soil the harvest will be notably diminished, and often it will be profitable to plow the soil for a new sowing.

In any case the chances for a successful crop vary very much with the date of the sowing, as we shall see by the study of the following table, which shows that in each year the season for sowing that is favorable to the crop of that year is very much restricted by the early arrival of the winter cold. Thus in 1871 the sowing was stopped on the 20th of October by the cold weather; in 1872 it continued throughout the autumn until the 29th of December; in 1880 it occurred on the 3d of November. Sometimes heavy rains prevent the sowing, but in 1881 neither cold nor rain prevented field work until the middle of December. [In order to save space I have omitted the elaborate tables of frosts, low temperatures, and rains given by Marié-Davy for each of these years and weeks.—C. A.]

The grain now arrives at the epoch of heading, at which the original stalk becomes several branches, each of which bears an immature head on which the rudimentary seed can already be counted under the microscope; the number of such seeds will not increase in the further development of the plant, but many of them may not come to maturity; therefore a careful count of these rudimentary seeds over a small area of the field would give a first estimate of the maximum possible crop.

According to Gasparin the length of time that elapses from the moment when the mean daily temperature of the air in the shade is  $5^{\circ}$  C. up to the date of heading of the wheat is such that the sum total of the mean daily shade temperatures is  $430^{\circ}$  C., but as the initial date is difficult to determine we shall in our calculations adopt the rule of Hervé Mangon, according to whom the sum of the mean daily temperature in the shade, rejecting all that are below  $6^{\circ}$  C. (at which the wheat does not vegetate), is  $640^{\circ}$  C. if we count from the date of sowing, or  $555^{\circ}$  C. if we count from the date of germination. The following table is computed by counting from the former date; a parallel computation from the latter date shows that on the

average of ten years there is no appreciable difference between the results.

*Duration, in days, from sowing to heading of winter wheat, at Montsouris, France.*

Date of sowing.	1872.	1873.	1874.	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	Average for 1872-1881.	
												Duration.	Date.
September 22 ...	152	67	87	58	91	57	61	167	160	85	154	99	Dec. 30
September 29 ...	158	72	116	113	147	64	110	171	161	92	159	120	Jan. 27
October 6 .....	161	80	161	155	153	84	135	180	161	136	157	141	Feb. 24
October 13 .....	168	90	164	172	164	88	140	173	164	147	155	147	Mar. 9
October 20 .....	168	133	163	175	163	107	138	178	164	148	150	154	Mar. 23
October 27 .....	163	140	162	174	160	106	145	185	164	147	152	155	Mar. 31
November 3 ....	162	141	158	172	156	107	156	182	162	141	146	154	Apr. 6
November 10 ...	155	140	158	171	159	108	156	175	158	128	146	151	Apr. 10
November 17 ...	148	134	153	163	156	123	150	168	153	141	144	149	Apr. 15
November 24 ...	141	134	148	159	160	125	147	162	147	135	141	145	Apr. 18
December 1 .....	134	136	142	154	143	123	143	156	140	131	136	140	Apr. 20
December 8 .....	127	132	135	148	136	120	138	149	133	127	129	135	Apr. 22
December 15 ....	120	126	128	141	129	115	131	142	126	124	122	128	Apr. 22
December 22 ....	113	129	121	134	124	111	126	135	119	126	118	124	Apr. 25
December 29 ....	106	127	114	127	120	106	120	131	112	123	111	118	Apr. 26

This table shows that on the average of ten years the seed that was sown, e. g., on the 27th of October and required one hundred and fifty-five days to head, is that which took the longest time; for sowings before that date, as well as after it, the durations steadily diminish; in other words, this sowing is that whose development was the most retarded by the winter cold. If we compare this table with those given by Marié-Davy, showing the frosts, we find a complete inversion in the chances of injury from frost; wheat as a green plant has as little to fear from frost as has the dry grain. But during and after the formation of the embryo seed, as well as during germination, on the contrary, frost is very injurious, and if the embryo is seized by frost it perishes. If this accident occurs it is possible that the progress of heading may permit a new formation of embryo to replace those which have perished. Such accidents must have occurred to the seed sown in the hope of reaping an early harvest in 1874, 1875, 1876, 1877, 1878, and 1881, but did not occur in 1882. This accident is not incompatible with an excellent harvest, as we see in the case of 1874, but it causes a decided retardation of the harvest, as in 1877. The mean of the ten years shows that the heading occurs at an epoch in the spring when the mean temperature of the air is between 6° and 13° C., and when the rainfall is generally abundant, so that at this epoch damage does not generally occur to the grain; only in case of the sowing of September 29, 1878, did the

heading occur during the very cold season likely to be injurious to vegetation.

We pass now to the period from the heading of the wheat to the flowering. According to the determination of Herve Mangon, the sum total of the mean daily air temperatures in the shade necessary to flowering is  $1,500^{\circ}$  C., counting from the date of sowing, or  $860^{\circ}$  if counted from the date of heading. If we consider the date thus fixed for the flowering we shall find that it corresponds to a mean daily temperature at that epoch of  $16.5^{\circ}$  C. on the average of many years; but if we consider the individual years we shall find the actual mean temperatures of that date to vary from  $8^{\circ}$  to  $22^{\circ}$  C., and also that for temperatures below  $13^{\circ}$  the flowering becomes uncertain, prolonged, and detrimental to the crop; but as to the upper limit,  $22^{\circ}$  C., there is no evidence that even higher temperatures will be injurious. The following table gives the calculated number of days that elapse from the sowing to the flowering, together with the average duration and the corresponding average date. The corresponding tables of mean temperatures and lowest temperatures at the date and the quantity of rainfall are omitted for want of space.

*Duration in days from the sowing to the flowering of winter wheat at Montsouris, France.*

Date of sowing.	1872.	1873.	1874.	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	Average for 1872-1881.	
												Duration.	Date.
September 22 ...	244	228	239	237	238	208	231	261	242	235	239	236	May 16
September 29 ...	248	226	237	238	242	209	229	259	239	235	239	236	May 23
October 6 .....	242	220	237	238	243	214	227	258	238	233	235	235	May 29
October 13 .....	241	225	234	234	240	217	222	251	236	231	232	233	June 3
October 20 .....	238	225	231	231	237	219	216	249	234	229	225	231	June 8
October 27 .....	232	222	226	226	232	215	210	249	232	224	222	227	June 12
November 3 ....	228	219	220	220	227	212	217	245	227	219	215	223	June 14
November 10 ...	221	217	218	218	223	206	215	238	223	214	214	219	June 17
November 17 ...	214	211	212	212	219	203	209	231	217	211	212	214	June 19
November 24 ...	207	207	208	208	213	198	206	224	211	205	208	209	June 21
December 1 .....	200	203	202	202	206	191	202	218	204	199	202	203	June 22
December 8 .....	198	200	195	195	199	188	197	211	197	195	196	197	June 23
December 15 .....	186	194	188	188	192	184	190	204	190	191	189	191	June 24
December 22 .....	179	189	181	181	186	177	183	197	183	186	183	184	June 24
December 29 .....	172	185	178	178	180	171	176	191	176	181	176	179	June 26

The ripening of wheat is perfected when the plant has received a sum total of mean daily air temperatures in the shade of  $815^{\circ}$  C. since the date of flowering. This result happens on the average of Paris forty-four days after flowering, and the individual irregularities scarcely ever exceed four or five days. Therefore the date of flower-

ing can be made the basis of a very close estimate of the date of ripening.

The date of flowering occurs at the time of the greatest vital activity of the plant, which at that time is actively drawing its nourishment from the soil and is transpiring, assimilating, and increasing in weight. But very soon this work is relaxed and is confined more and more to the interior of the plant, conveying into the seed the elaborated materials formed within the leaves and stems. It is especially in this latter part of the life of the plant that the internal consumption can exceed the gain from without, and the plant tends to diminish its dry weight.

This period has a great influence on the final result, not only because the plant can gain as a whole, but especially because of the distribution which is made within it of the material which it has brought together. The straw has only a secondary value. It is the seed which constitutes nearly the whole value of the harvest. Therefore all that passes from the straw to the grain is a benefit, though this passage should be accompanied by a notable consumption of the nutritious materials of the stalk. It is neither the state of preparation of the stalk, nor the heat, nor the radiation, nor the moisture which of itself alone produces the best quality of grain. There must be a reunion of all these various elements in a proper proportion, which latter will vary with the weather and with the locality even with the same weather. The blighting of wheat is an accident that one dreads most at this period. The blight, properly so called, is due to a temperature and a radiation that is too intense for the movement of the sap in the plant; the seed has not time to receive the sum total of the nourishing particles that have been prepared for it; therefore it becomes small, lean, and shriveled up. A greater sum total of moisture in the soil or a less active transpiration would have given a better result. But we often confound the blight, properly so called, with the analogous result produced by an insufficient assimilation or elaboration of the various materials that go to make up the wheat grain or by a disproportion in the relative quantities of the elements that should make up the seed.

The following table shows the number of days elapsing from sowing to ripening for the dates adopted in the previous tables. It is calculated by first ascertaining the number of days elapsing from flowering to ripening according to the rule above given and then adding these intervals to those already calculated for the flowering.

*Duration, in days, from sowing to ripening, for winter wheat at Montsouris, France.*

Date of sowing.	1872.	1873.	1874.	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	Average for 1872-1881.	
												Duration.	Date.
												Days.	
September 22...	291	282	284	285	287	268	281	311	292	285	290	287	July 6
September 29...	290	279	287	285	287	264	279	308	293	284	289	286	July 12
October 6 .....	287	277	279	284	285	263	275	306	286	281	285	282	July 15
October 13 .....	283	274	276	281	281	263	272	299	282	277	281	279	July 19
October 20 .....	279	271	272	280	277	262	268	296	279	273	276	276	July 23
October 27 .....	272	267	269	276	272	258	265	296	275	267	271	272	July 26
November 3 .....	269	263	265	272	266	255	261	290	271	261	264	267	July 28
November 10 .....	262	260	259	269	262	249	258	283	266	255	263	262	July 30
November 17 .....	255	254	255	263	257	245	252	276	260	252	259	257	Aug. 1
November 24 .....	248	249	249	257	250	240	248	270	254	247	254	251	Aug. 2
December 1 .....	241	244	242	251	243	234	243	263	247	241	258	245	Aug. 3
December 8 .....	234	240	235	245	236	232	234	256	240	235	241	239	Aug. 4
December 15 .....	227	234	228	238	229	231	232	249	233	231	234	233	Aug. 5
December 22 .....	220	229	221	231	225	226	225	242	226	226	229	227	Aug. 6
December 29 .....	213	226	217	224	219	220	218	236	219	220	222	221	Aug. 7

In the following table I present a summary of the preceding details, showing the average duration and dates for the ten years from 1872 to 1881, inclusive. To this I have added the average total daily radiation for crops sown in 1873 to 1880, as computed by Marié-Davy in actinometric degrees for two phases, viz, from heading to flowering, and for thirty days after flowering, which brings us through the greater and more important part of the ripening phase.

*Summary of dates and radiation for winter wheat during ten years, 1872-1881, at Montsouris, France.*

Date of sowing.	Average interval from sowing to—				Average date of germination.	Average date of heading.
	Germination.	Heading.	Flowering.	Ripening.		
	Days.	Days.	Days.	Days.		
September 22 .....	7	99	236	287	Sept. 29	Dec. 30
September 29 .....	7	120	236	286	Oct. 6	Jan. 27
October 6 .....	8	141	235	282	Oct. 14	Feb. 24
October 13 .....	8	147	233	279	Oct. 21	Mar. 9
October 20 .....	11	154	231	276	Oct. 31	Mar. 23
October 27 .....	20	155	227	272	Nov. 16	Mar. 31
November 3 .....	20	154	223	267	Nov. 23	Apr. 6
November 10 .....	33	151	219	262	Dec. 13	Apr. 10
November 17 .....	36	149	214	257	Dec. 23	Apr. 15
November 24 .....	37	145	209	251	Dec. 31	Apr. 18
December 1 .....	42	140	203	245	Jan. 12	Apr. 20
December 8 .....	41	135	197	239	Jan. 18	Apr. 22
December 15 .....	35	128	191	233	Jan. 19	Apr. 22
December 22 .....	38	124	184	227	Jan. 29	Apr. 25
December 29 .....	34	118	179	221	Feb. 1	Apr. 26

*Summary of dates and radiation for winter wheat during ten years, 1872-1881,  
at Montsouris, France—Continued.*

Date of sowing.	Average date of flower- ing.	Average date of ripening.	Average total radiation, in actinometric degrees, 1874- 1881.		
			Flower- ing stage.	Ripen- ing stage.	Sums.
September 22 .....	May 16	July 6	2,562	1,344	3,906
September 29 .....	May 23	July 12	2,681	1,308	3,989
October 6 .....	May 29	July 15	2,840	1,276	4,116
October 13 .....	June 3	July 19	2,817	1,341	4,158
October 20 .....	June 8	July 23	2,751	1,380	4,131
October 27 .....	June 12	July 26	2,735	1,385	4,120
November 3 .....	June 14	July 28	2,739	1,388	4,127
November 10 .....	June 17	July 30	2,731	1,400	4,131
November 17 .....	June 19	Aug. 1	2,705	1,426	4,131
November 24 .....	June 21	Aug. 2	2,704	1,427	4,131
December 1 .....	June 22	Aug. 3	2,668	1,438	4,106
December 8 .....	June 23	Aug. 4	2,678	1,442	4,120
December 15 .....	June 24	Aug. 5	2,690	1,438	4,128
December 22 .....	June 24	Aug. 6	2,613	1,432	4,045
December 29 .....	June 26	Aug. 7	2,595	1,423	4,018

On the average the wheat sown October 13 and ripening July 19 received the most sunshine during the last two stages and should give the best crop.

The preceding study gives the details of the weather and the development of the wheat from 1872 to 1882. Marié-Davy compares these figures with the annual reports of the total crops actually gathered in the Department of Seine-et-Oise, immediately surrounding Montsouris, as shown in the following table, assuming that the crop ripened at any time between July 6 and August 7 during those years.

*Wheat crops and sunshine at Montsouris.*

Year of harvesting.	Crop hectoli- ters per hectare.	Total ac- tinometric degrees during flowering and ripen- ing stages.	Year of harvesting.	Crop hectoli- ters per hectare.	Total ac- tinometric degrees during flowering and ripen- ing stages.
1872 .....	31.0		1880 * .....	24.4	4,154
1873 .....	17.3		1881 * .....	24.6	4,351
1874 * .....	23.9	4,494	1882 * .....	26.8	3,941
1875 † .....	21.9	3,892	* Average of 5 good years .....	25.9	4,284
1876 * .....	25.0	4,416			
1877 † .....	23.0	4,140	† Average of 4 poor years .....	20.4	3,827
1878 † .....	19.4	3,584			
1879 † .....	17.9	3,703			

If we summarize the five years of crops above the mean and the four years of crops below the average, as indicated in the preceding



table, there results an apparent confirmation of our view that the radiation during the flowering and ripening phases has an important, direct influence; in fact, the diminution of the average sunshine from 4,284 to 3,827 actinometric degrees has been accompanied by a diminution of the crop from 25.9 to 20.4 hectoliters per hectare. This diminution of 25 per cent of the crop corresponds to a loss of about 1.2 hectoliters per hectare, or 4 per cent of the normal crop, for every 100 actinometric degrees.

We have already seen that if we suppose the same number of stalks to the hectare and the same relative total sum of solid nutriment taken from the soil by each stalk, then, according to theory, the radiation can serve as a measure of the possible work of assimilation by the plant, and consequently of the actual sum total of the assimilated material. These conditions are never completely realized for many reasons, and one can not hope for an exact relation between the crop and the radiation, but it is interesting to see that the above-reported crops, both in detail and general averages, confirm the theory.

Some of the minor departures from perfect agreement are explained by a detailed examination of the conditions during the successive phases of germination, heading, flowering, and ripening during the good years and the poor years. The following table gives the average climatic conditions during the first three phases and shows that as between the good and bad years there can have been but slight average differences in the condition of the stalks and the embryo seeds up to the beginning of the ripening stage, as far as it depends on climatic conditions.

*Comparison of climates during five good and four poor years.*

Stage.	Good years.	Poor years.
<b>Germinating period:</b>		
Duration ..... days..	28	23
Freezing weather ..... days..	11.6	9.0
Average minimum temperatures ..... ° C..	— 4.66	— 3.7
Rainfall during the period ..... millimeters..	9.4	11.6
<b>Heading period:</b>		
Duration ..... days..	114	113
Freezing weather ..... days..	5.7	6.1
Average of the minimum temperatures ..... ° C..	— 1.7	— 2.1
Average temperature at the epoch of heading ..... ° C..	10.1	9.7
Average rainfall at the epoch of heading ..... millimeters..	14.8	22.1
<b>Flowering period:</b>		
Duration ..... days..	75	80
Mean daily temperature at the epoch of flowering ..... ° C..	16.8	16.3
Average rainfall at the epoch of flowering ..... millimeters..	26.3	31.6
Average radiation during this period ..... Actinometric degrees..	2,826	2,525
<b>Ripening period:</b>		
Average radiation during this period ..... Actinometric degrees..	1,458	1,302

The preceding table shows that the only important difference between these good and poor years consists in the fact that the latter have more rain and less sunshine. The influence of the temperature of the air as such and of the number of days of freezing weather does not seem to be important, so that we must conclude that the cloudy weather which accompanies the rain and cuts off the sunshine, affects the plant unfavorably only by this loss of radiation. A deficiency of light is more unfavorable than excessive moisture in the soil. In general in France, and especially in dry countries such as the arid regions of America, it is the deficiency of water in the soil that affects the crops unfavorably. Where an abundance of sunshine exists the wheat plant can utilize more water than ordinary soils possess; hence the great advantage of irrigation, as long since practiced in Mesopotamia, Egypt, China, India, Arizona, and South Africa. The numerical data with regard to the quantity of water and the times of irrigation have been approximately determined at agricultural experiment stations, with results given in the next section of this present report.

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In the *Annuaire* for 1890 Marié-Davy gives climatic tables especially adapted for phenological study.

In order that meteorological data may be presented in form convenient for the comparison of crop reports or for the prediction of the future development of the current crop or for other studies in the growth of plants it is necessary that the data should be compiled in a manner very different from that ordinarily given in climatological tables. The monthly means and other data given in the so-called international form recommended and urged by the recent international conferences of Europe have much more regard to dynamic meteorology and to questions in hygiene than to questions in agriculture. For our agricultural studies a continuous summation must be made from the beginning to the end of the year, either by decades, by weeks, by pentads, or even by days for each successive year. From such tables we can calculate the total work that has been done upon the plant by the sunshine and the work that remains to be done before the harvest. Such tables can be compiled in an empirical approximate way from the data furnished by the international forms, as I have attempted to do in table—<sup>a</sup>. But it is far better to prepare them from the original records, and they must be prepared for every agricultural experiment station in the United States before we can profitably study the influences of our

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<sup>a</sup> This table is omitted in the present edition.

climates upon our crops. These tables must include at least the following data:

1. The mean temperature of the air in the shade. This may be deduced most simply from the average of the daily maximum and minimum temperatures.

2. The mean temperature of a thermometer, preferably a black bulb, but not in vacuo, exposed to the full sunshine and wind and placed amid the foliage of the trees or the blades of the grain that is to be studied, so that its temperature may be approximately that of the plant. This should also preferably be obtained by using maximum and minimum thermometers.

3. The temperature of the soil at depths of 1 inch and 6 inches, corresponding to the depths of the roots of the plants.

4. The hygrometric condition of the free air, which may be expressed either as relative humidity or as dew point or as vapor tension. The latter will be most convenient in all our calculations.

5. The velocity of the wind or its daily movement.

6. The cloudiness of the sky. This may be obtained from the ordinary estimates of cloudiness if these are made very frequently, but with more ease and accuracy from some form of sunshine recorder.

7. The total effective radiation from sun and sky. This may be obtained from frequent observations of the Marié-Davy actinometer or the so-called Arago-Davy conjugate thermometer, or Violle's conjugate bulbs, but still better when these are made self-recording, and better yet from such forms of apparatus as the photantitupimeter or phantupimeter of Marchand, or the radiometer of Bellani, which Marié-Davy has improved upon in the form described by him as the vaporization lucimeter. (See *Annuaire de Montsouris*, 1888, p. 207, or 1890, p. 61.) The methods of using these instruments are doubtless subject to improvement, but these or some more delicate substitutes are absolutely necessary in order to enable us to appreciate the work done by solar radiation. In the absence of instruments we may use the maximum sunshine as diminished by the estimated cloudiness.

8. The actual evaporation from plants and soils, or in lieu of this the evaporation recorded by the Piche or even older forms of evaporimeters whose records are doubtless closely parallel to those of the plants in the soil, but usually largely in excess of these.

9. The total rainfall as measured by the ordinary rain gauges in the experimental field.

As an illustration of the convenience of such tables I have compiled the following table for Montsouris by pentads in so far as the data is given by pentads by Descroix in the *Annuaire* for 1890. Some of the data is obtained by interpolation from monthly values

and some columns are left blank to show that they are still desirable.<sup>a</sup> The pentads or decades to be used in such a table as this should always be those introduced by Dove, the limiting dates of which are as given in this table; the twelfth pentad of the ordinary year has five days, but that of the leap year has six days, so that the limiting dates are always as here given, viz, from February 25 to March 1, inclusive. The data given by Descroix in the *Annuaire* for 1890 consist of the mean values for the respective pentads. From these I have constructed the sum totals from January 1 to date, which are needed in agriculture, and which are still more easily obtained when we have the original tables of observations at hand, by simply taking the sums in a continuous series and avoiding the labor of computing the means. From such a table of sum totals we obtain the sum between any two dates by subtracting the sum for the earlier from that for the later date.

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<sup>a</sup>The omitted columns are: (1) Sunshine; actual duration. (2) Actinometric degrees; actual daily average. (3) Ratio of actual actinometric degrees to the maximum possible daily average. (4) Soil temperature at the surface. (5) Soil moisture. (6) Percentage of saturation.

Data, by pentads, for Montsouris, 1889, as published by Descroix or specially computed.

Dove's pentad limits.	No.	Sun's location.		Sunshine.		Actinic degree--maximum possible.		Shade temperature.		Sun temperature (daily maximum).	Relative humidity.	Vapor tension.	Hourly wind velocity.	Total daily evaporation.	Total rainfall.
		Dec'l.	Zen. distance.	Maximum duration.	Average cloudiness.	Noon.	Daily average.	Daily mean.	Daily maximum.						
										°	°	h.	Tenths.		
1889.															
January 1-5.....	1	-22.7	71.5	8.3	1	63.7	31.7	-1.0	+1.1	3.2	70.0	3.10	12.4	Frozen	0.0
January 6-10.....	2	-22.0	70.8	8.4	4	67.7	32.5	+0.6	4.5	6.4	77.6	4.26	9.5	Frozen	9.1
January 11-15.....	3	-21.2	70.0	8.6	10	68.4	33.4	1.2	2.1	3.2	81.7	4.18	18.7	Frozen	5.4
January 16-20.....	4	-20.2	69.0	8.8	7	69.5	34.5	1.0	3.0	4.8	81.4	4.22	8.2	Frozen	6.9
January 21-25.....	5	-19.1	67.9	9.0	7	70.5	35.6	2.3	3.9	5.9	78.1	4.44	12.6	3.61	2.4
January 26-30.....	6	-17.8	66.6	9.2	8	71.3	36.8	4.1	6.4	10.7	71.3	4.60	12.7	6.45	5.7
January 31-February 4.....	7	-16.7	65.5	9.4	8	73.0	38.0	6.4	7.7	11.4	77.7	5.84	21.4	8.85	9.8
February 5-9.....	8	-15.1	63.9	9.7	7	74.2	39.3	2.7	5.5	8.5	71.0	4.18	21.1	Frozen	11.2
February 10-14.....	9	-13.5	62.3	10.0	5	75.4	40.4	0.3	6.3	8.1	73.4	3.96	19.1	Frozen	26.2
February 15-19.....	10	-11.8	60.6	10.3	8	76.4	41.5	6.5	9.1	14.7	71.3	5.54	16.2	9.10	3.0
February 20-24.....	11	-10.0	58.8	10.6	8	77.5	42.6	+2.7	4.0	8.6	74.0	4.42	20.1	Frozen	9.9
February 25-March 1.....	12	- 8.2	57.0	10.8	7	78.5	43.8	-0.4	1.8	7.8	65.9	3.02	11.9	Frozen	3.2
March 2-6.....	13	- 6.2	55.0	11.2	3	79.3	45.1	-0.6	3.9	10.9	62.3	2.94	9.9	Frozen	0.0
March 7-11.....	14	- 4.3	53.1	11.4	9	80.2	47.0	7.1	10.9	17.1	71.9	5.94	22.3	3.05	12.2
March 12-16.....	15	- 2.3	51.1	11.8	7	81.0	49.7	3.8	7.1	15.2	59.9	3.94	15.7	Frozen	0.5
March 17-21.....	16	- 1.4	49.2	12.0	9	81.6	53.1	8.2	12.0	22.4	68.7	5.96	15.4	Frozen	12.0
March 22-26.....	17	+ 1.6	47.2	12.4	7	82.3	56.0	5.9	9.8	18.4	63.5	4.80	18.2	Frozen	2.7
March 27-31.....	18	+ 3.6	45.2	12.6	9	82.9	58.7	7.0	10.0	17.3	69.5	5.44	13.1	Frozen	0.9
April 1-5.....	19	+ 5.5	43.3	13.0	8	83.4	61.0	7.0	10.3	19.2	70.0	8.40	14.2	12.05	13.8
April 6-10.....	20	7.4	41.4	13.3	8	83.7	63.7	9.8	14.8	23.9	63.2	6.06	9.7	9.65	20.1
April 11-15.....	21	9.2	39.6	13.5	9	84.1	65.8	8.1	11.5	27.0	66.2	5.62	11.0	11.40	7.3
April 16-20.....	22	11.0	37.8	13.8	6	84.5	67.8	8.6	13.8	23.6	60.8	6.14	13.9	20.40	0.0
April 21-25.....	23	12.7	36.1	14.2	7	84.8	69.5	11.2	15.6	30.9	59.8	6.30	17.4	20.25	7.3
April 26-30.....	24	14.3	34.5	14.4	8	85.2	71.0	11.8	16.4	32.9	61.5	6.82	11.0	15.20	8.9
May 1-5.....	25	15.8	33.0	14.6	6	85.4	72.1	12.8	18.5	31.9	59.9	7.73	9.4	15.00	5.5
May 6-10.....	26	17.2	31.6	14.9	7	85.5	73.3	14.8	19.4	32.9	61.3	9.02	11.5	12.00	9.6

Data, by pentads, for Montsouris, 1889, as published by Desceirois or specially computed—Continued.

Dove's pentad limits	No.	Sun's location.		Sun's position.		Sun's temperature.		Sun's relative humidity.		Sun's wind velocity.		Sun's total daily evaporation.		Sun's total rainfall.	
		Dec'l.	Zen. distance.	A.	Tenth.	°	°	°	°	°	°	°	°	mm.	mm.
1889.															
May 11-15	27	18.5	30.3	16.1	7	58.7	74.0	20.3	37.8	37.4	8.56	7.2	14.80	4.1	
May 16-20	28	19.7	29.1	15.4	8	58.8	74.8	18.4	38.4	38.0	8.74	9.1	12.15	7.4	
May 21-25	29	20.7	28.1	14.5	6	58.9	75.4	17.9	27.8	40.9	11.08	9.0	14.15	4.8	
May 26-30	30	21.5	27.3	13.7	7	59.0	75.9	16.3	20.5	33.8	9.92	12.4	15.30	44.7	
May 31-June 4	31	22.8	26.5	12.9	5	59.2	76.3	17.3	22.2	37.4	11.10	9.5	13.95	12.6	
June 5-9	32	23.8	25.0	12.0	5	59.3	76.5	21.1	25.3	48.1	14.02	11.3	19.40	19.6	
June 10-14	33	23.2	25.6	12.0	5	59.3	76.7	16.5	20.3	38.8	9.70	13.8	20.60	8.5	
June 15-19	34	23.4	25.4	12.1	5	59.3	76.8	13.4	23.3	42.5	10.80	14.7	24.65	1.2	
June 20-24	35	23.4	25.4	12.1	3	59.3	76.9	19.4	24.6	45.8	10.76	11.4	23.65	3.6	
June 25-29	36	23.3	25.5	12.1	4	59.3	76.8	20.3	23.1	41.4	10.95	10.6	27.15	0.8	
June 30-July 4	37	23.0	25.8	12.0	3	59.3	76.7	18.8	24.5	37.6	10.18	14.4	28.35	0.0	
July 5-9	38	22.6	26.2	11.9	5	59.2	76.4	19.9	25.3	39.0	12.02	14.4	25.60	8.5	
July 10-14	39	21.9	26.9	11.3	8	59.1	76.1	20.6	25.4	41.0	13.64	11.4	14.65	13.8	
July 15-19	40	21.1	27.7	10.5	7	59.1	75.7	16.8	21.5	35.5	9.24	12.3	19.15	1.0	
July 20-24	41	20.2	28.6	10.5	8	58.9	75.1	17.8	23.8	38.3	9.32	14.3	20.30	1.3	
July 25-29	42	19.1	29.7	10.2	9	58.7	74.4	16.9	20.4	32.3	10.52	14.3	16.55	9.6	
July 30-August 3	43	17.9	30.9	10.0	5	58.6	73.7	20.0	26.8	39.4	12.25	9.3	19.35	0.0	
August 4-8	44	16.6	32.2	14.3	6	58.5	73.7	18.7	24.0	33.8	11.22	11.0	20.00	0.1	
August 9-13	45	15.2	33.6	14.5	7	58.3	73.1	17.3	22.1	34.9	10.18	14.2	18.40	10.7	
August 14-18	46	13.6	35.2	14.3	7	58.0	70.3	18.5	21.3	38.6	11.00	14.7	16.45	0.7	
August 19-23	47	12.0	36.8	14.0	8	57.7	69.9	17.0	21.5	30.1	11.34	21.9	12.65	26.8	
August 24-28	48	10.8	38.5	13.7	5	57.4	67.0	14.0	18.7	30.2	8.54	9.3	9.35	7.1	
August 29-September 2	49	8.5	40.3	13.4	2	57.0	65.2	20.6	27.4	38.9	12.34	6.1	17.00	0.1	
September 3-7	50	6.7	42.1	13.1	7	56.8	62.8	18.5	22.8	37.6	11.14	9.0	16.25	1.4	
September 8-12	51	4.5	44.0	12.8	2	56.1	60.1	13.7	26.0	33.5	10.46	4.9	14.85	0.0	
September 13-17	52	2.9	45.9	12.6	4	55.0	55.0	12.9	17.9	27.6	8.32	13.1	27.10	0.0	

September 18-22	53	+ 0.9	47.9	12.3	6	83.0	55.3	11.7	16.1	26.6	62.4	7.14	10.7	14.50	9.8
September 23-27	54	- 1.0	49.8	12.0	4	81.4	51.9	11.4	16.6	27.3	59.9	6.76	10.4	13.85	0.8
September 28-October 2	55	- 3.0	51.8	11.7	9	80.7	48.5	11.4	15.4	21.6	70.8	7.50	9.1	9.10	12.6
October 3-7	56	- 4.9	53.7	11.4	7	80.0	46.8	10.9	15.3	23.5	72.8	7.98	14.7	6.85	4.8
October 8-12	57	- 6.8	55.6	11.1	7	79.2	44.4	11.1	14.4	22.4	72.9	7.64	17.5	8.45	23.5
October 13-17	58	- 8.7	57.5	10.8	5	78.2	43.2	10.3	15.2	24.3	71.2	8.08	11.3	7.00	1.6
October 18-22	59	- 10.5	59.3	10.5	8	77.2	42.3	11.1	14.0	21.3	73.9	7.64	14.1	6.30	21.9
October 23-27	60	- 12.3	61.1	10.2	7	76.1	41.2	9.6	12.8	16.8	75.7	7.28	14.3	6.50	7.3
October 28-November 1	61	- 13.9	62.7	9.9	5	75.0	40.1	10.5	14.6	21.9	71.3	7.62	11.8	9.15	5.8
November 2-6	62	- 15.5	64.3	9.6	7	74.0	38.8	9.3	12.4	15.8	74.6	6.88	13.4	7.28	14.6
November 7-11	63	- 17.0	65.8	9.4	8	72.8	37.4	10.3	12.8	15.3	77.3	7.62	8.3	6.45	0.4
November 12-16	64	- 18.3	67.1	9.1	2	71.6	36.2	7.3	12.9	15.9	75.7	6.54	6.9	4.85	0.0
November 17-21	65	- 19.6	68.4	8.9	8	70.6	35.3	4.2	6.6	7.5	83.9	5.48	5.9	Frozen	0.3
November 22-26	66	- 20.7	69.5	8.7	5	69.0	34.3	5.7	10.1	11.0	78.2	5.92	16.3	Frozen	6.4
November 27-December 1	67	- 21.6	70.4	8.5	7	68.4	33.2	2.2	4.6	7.4	70.9	3.92	15.4	Frozen	6.9
December 2-6	68	- 22.3	71.1	8.4	4	67.4	32.4	- 1.6	0.6	2.3	73.4	3.14	14.6	Frozen	6.0
December 7-11	69	- 22.9	71.7	8.3	9	66.7	31.6	+ 1.0	2.8	4.3	81.4	4.06	12.3	Frozen	10.8
December 12-16	70	- 23.3	72.1	8.2	7	66.2	31.2	0.2	2.7	3.3	83.0	3.92	8.7	Frozen	4.5
December 17-21	71	- 23.4	72.2	8.2	10	65.9	30.9	1.0	2.7	2.2	90.9	4.24	13.4	Frozen	0.3
December 22-26	72	- 23.4	72.2	8.2	8	66.0	31.0	7.1	9.6	10.4	84.7	6.52	18.6	Frozen	10.7
December 27-31	73	- 23.2	72.0	8.2	8	66.2	34.3	- 0.4	1.6	1.9	80.3	3.60	10.2	Frozen	0.0
January 1-5	74	- 22.7	71.5	8.3		66.7	34.7								



**THE RESULTS OF RECENT STUDIES BY ANGOT.**

In 1880 the Central Meteorological Bureau of France, under the minister of public instruction, organized a system of phenological observations; the resulting data have been studied by Angot in a series of memoirs.

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In his first paper (1882) Angot grouped the dates of the wheat harvest as observed during 1880 and 1881 at several hundred stations in France in groups of four or five stations and plotted these upon maps showing the elevations of the stations. By a careful comparison of neighboring stations he shows that the date of the harvest is everywhere quite uniformly retarded with increase of elevation, and at the rate of four days in time for every hundred meters of ascent. Apparently this retardation is the general result of a complex system of influences in which rainfall, drainage, soil, sunshine, temperature, and other local peculiarities combine. It is evident that the special influence of any local climate on the crop can not be successfully studied until the observations have been corrected for the general influence of elevation. He therefore reduces all the dates of harvest to sea level by applying the preceding correction.

A similar calculation showed him that the phenomena of flowering are also retarded at precisely the same rate of four days per 100 meters of elevation and these dates also are thus reducible to sea level.

Angot's charts, showing the dates of flowering and harvesting thus reduced to sea level, show great regularity and the isanthesic lines show the perfect regularity with which the reduced epoch of flowering begins in southern France on the 11th of May and advances northward until it reaches the northern boundary of France on the 25th of June; in a similar way the harvesting of winter wheat begins in southern France on the 10th of June (reduced epoch) and in northern France on the 9th of August. The variations of these isanthesic lines from year to year may be compared with the ordinary charts of temperature reduced to sea level or with other meteorological data in a very simple manner.

Angot has modified and apparently improved the methods of determining the influence of temperature on the date of flowering and harvesting. He says that since 1837 Boussingault's idea that the ripening demands a certain sum total of heat, which is constant for each species of plant, has been generally adopted. At first this sum total was calculated by adding together all mean daily temperatures from the germination of the seed or the beginning of vegetation after rejecting such means as were below freezing point. Then, as C. H. Martins, De Gasparin, and A. de Candolle had shown

that the temperatures useful to the plant vary with the species and are decidedly above freezing, therefore students have taken other limits. Thus Gasparin and Hervé Mangon adopt  $6^{\circ}$  C. for the initial temperature in the growth of wheat. In order to ascertain the proper method of counting temperatures Angot has accomplished the labor of prosecuting three parallel computations by three different methods, as follows:

(A) *First method*.—By observations of daily maximum and minimum temperatures. In this method Angot has examined separately the observed maxima and minima of the thermometer in the shade. After rejecting all observations below  $6^{\circ}$  C., he subtracts  $6^{\circ}$  C. from all the others and takes the separate sums of the remaining maxima and minima for each month and then the average of these two sums, which consequently represents a sum total of heat received during the month in excess of  $6^{\circ}$  C.

(B) *Second method*.—By the daily means. In this method the mean of each day is first computed by taking the average of the maximum and minimum;  $6^{\circ}$  C. is then subtracted from each of these daily means and all negative remainders are rejected. The sum of the positive remainders represents the sum total of heat received in excess of  $6^{\circ}$  C.

(C) *Third method*.—By maximum temperatures alone. In this method, which is a modification of that proposed by Hoffmann, a maximum thermometer is exposed to the direct rays of the sun and the sum total of the maximum temperatures is used by Hoffmann. But Angot prefers to use the maximum thermometer in the shade, as in the first method, and, as before, takes the sum total of all the positive remainders after subtracting  $6^{\circ}$  C.

In all these methods the principal difficulty is to fix the epoch from which the summation should begin. Sometimes the date of sowing has been adopted as this epoch, but from the date of sowing up to the date of sprouting the seed and the young plant are subjected only to the temperature of the soil, and not to that of the air, which often differ considerably. It would perhaps be better to start with the date at which the plant appears above the earth, but the date of sprouting is not generally given by observers. He therefore provisionally adopts the 1st of December as the point of departure and calculates the sum total of temperatures for the nine stations in France for which the dates of flowering and harvesting of winter wheat have been best determined for the years 1880 and 1881. The agreement among themselves of the numbers calculated by these three methods for nine stations and two different years is such that no decision can be arrived at as to which method is the best, and such decision is reserved for a future study of other harvests.

A similar elaborate study of the harvest of rye gave the following results:

(1) Retardation for altitude is approximately four days per 100 meters, with some indication that the correct figure is rather less than this.

(2) The date of harvest reduced to sea level begins with the 5th of June in southern France and ends with the 25th of July on the northern border.

(3) The sum total of temperatures computed by the three methods A, B, C, above mentioned, shows that whatever method be finally adopted as the best, these sums are less for rye than for winter wheat.

A similar study for spring barley shows the following results:

(1) A retardation of four days per 100 meters of altitude sufficiently harmonizes the observations.

(2) A retardation of thirty or forty days in the date of sowing has no appreciable effect on the date of harvest, which varies from the 20th of June in southern France to the 14th of August on the northern boundary.

(3) The sum total of temperatures from sowing to harvest is too variable to be determined.

A similar study of the flowering of the narcissus (*Narcissus pseudonarcissus*) shows that the retardation of the date of flowering is at the rate of four to five days per 100 meters, and four days can be adopted without notable error.

A study of the currant (*Ribes rubrum*) shows that the retardation is between three and four days per 100 meters. The sum total of heat from December 1 up to the date of flowering, as deduced by the second and third methods, but under three different assumptions—i. e., that the initial temperature is 4°, 6°, 8°, respectively, seems to show that 4 is the proper figure for this plant.

A study of the flowering of the lilac shows that a retardation of four days per 100 meters best satisfies the observations of both leafing and flowering. The latter begins in southern France on the 22d of March and ends in northern and eastern France on the 6th of May. The calculation of the heat required for leafing shows that the most accordant results are obtained when we take the sum of maximum daily temperatures above 4° C. and count from the date of the last heavy frost, which sum is about 360° C. For the flowering, on the contrary, we have to take the sums of the mean daily temperatures, counting from 4° C. and from the same date of frost, which sum is then 350° C., while the sum of the maximum daily temperatures would have given 695° C.

A study of the leafing and flowering of the horse-chestnut (*Æsculus hippocastanum*) shows that the retardation of four days per 100 meters also satisfies these observations. The dates of leafing, as

reduced to sea level, begin with March 12 in southern France and extend to April 21 in northern France. The dates of flowering begin with April 6 in southern France and extend to May 16 in northern France.

The sums of temperatures are counted from the last severe frost, and the most accordant results are obtained when the sums of daily maxima are taken, counting from 2° C. The sum total is 715° to date of leafing, and from leafing to flowering 1,070°.

The leafing of the birch is found by Angot to have the same rate of retardation—very little less than four days per 100 meters—and the reduced epochs of leafing begin the 9th of March at the southeast corner of France and extend to the 16th of April at the northern border. The sums of temperatures up to the time of leafing are best computed by taking the sums of daily maxima above 2° C., but are very uncertain.

The leafing of the common oak (*Quercus pedunculata*) has a retardation of four days per ascent of 100 meters, and the reduced epochs begin with the 6th of April in southern France and end with the 6th of May in northern France. We can provisionally admit that the leafing of the oak occurs when the sum of the maximum daily temperatures has attained 940° C., counting above 2° C. and from the date of the last heavy frost.

The flowering of the elder (*Sambucus nigra*) has an approximate retardation of four days per 100 meters. The reduced dates begin on the 6th of April in southern France and end on the 10th of June in northern France. The flowering of the elder occurs when the sum of the mean daily temperatures since the date of the last frost has attained 840° C. if we count from 2°, or 630° if we count from 4° C.

The flowering of the common linden (*Tilia europæa*) or the *Tilia silvestris* is retarded three days per 100 meters' ascent for the mountainous countries, but four days is adopted for the whole of France, and the reduced dates of flowering begin with the 1st of May in southeastern France and extend to the 20th of June in northern France. The flowering of the linden occurs when the sum of the mean daily temperatures, counting from the last heavy frost and above 2° C., has attained 1,090° C.

It would seem to result from all this that the leafing of the trees and shrubs occurs when the sum total of the maximum daily temperatures, counting above a certain limiting value and from the date of the last heavy frost, has attained a certain value characteristic of each plant. But for a certain number of plants the flowering seems rather to depend on the sum of the mean daily temperatures.

In his second memoir Angot (1886) studied the additional data for the years 1882 and 1883. A new determination of the influence of altitude on the epoch of leafing again gave an average retardation of four days for each 100 meters of altitude for the lilac, the chestnut, the birch, and the oak. The average mean daily temperature of the air at the date of leafing varies between  $5^{\circ}$  and  $12^{\circ}$  C. for the lilac, with an average of  $9.1^{\circ}$ ; from  $4^{\circ}$  to  $14^{\circ}$  C., with an average of  $10.1^{\circ}$ , for the chestnut; from  $7^{\circ}$  to  $15^{\circ}$  C., with an average of  $10.7^{\circ}$ , for the birch; from  $5^{\circ}$  to  $16^{\circ}$ , with an average of  $11.3^{\circ}$ , for the oak. These ranges are so large that it is impossible to indicate any simple relation between the leafing of these plants and the mean daily temperature at this epoch. The mean of the daily maxima were also computed for the epoch of leafing, and were  $14.6^{\circ}$  for the lilac,  $15.7^{\circ}$  for the chestnut,  $16.1^{\circ}$  for the birch, and  $16.4^{\circ}$  for the oak. But again the variations were too large to attach any phenological importance to these numbers.

As to the sum total of temperatures Angot adopts, not a constant date, as December 1 or January 1, but dates that are variable for each station and each year and approximately represent the close of the last period of freezing weather. They vary in this case between the 18th of January and the 13th of February. After laborious calculations by different methods and starting from different initial temperatures he concludes that the leafing of the four plants under consideration occurs when the sum of the mean daily temperatures, counted from  $0^{\circ}$  C., or the sums of the maximum daily temperatures, counting from  $0^{\circ}$  C. and beginning at the date of the commencement of vegetable growth as above defined, attains the values given in the following table:

Plant.	Sums of daily means.	Sums of daily maxima.
	$^{\circ}$ C.	$^{\circ}$ C.
Lilac .....	333	550
Indian chestnut .....	522	845
Birch .....	517	898
Oak .....	677	1,082

In order to decide which of these two modes of calculation, daily mean or daily maxima, are most proper it will be necessary to operate upon a much longer series of observations.

The flowering of the narcissus, the lilac, the chestnut, the elder, and the linden was studied in a manner similar to that of the leafing. The retardation for altitude is, as before, four days to the 100 meters. The mean daily temperature at the date of flowering is: For the narcissus,  $6^{\circ}$  to  $14^{\circ}$  C., average  $9.4^{\circ}$ ; for the lilac, from  $8^{\circ}$  to  $15^{\circ}$  C.,

average 12.2°; for the chestnut, 8° to 16° C., average 12.0°; for the elder, 9° to 20° C., average 13.9°; for the linden, 12° to 21° C., average 16.4°. The mean daily maximum temperatures at the date of flowering for these same plants is as follows:

Plant.	Daily maxima.		Daily mean.	
	Range.	Mean.	Range.	Mean.
	° C.	° C.	° C.	° C.
Narcissus.....	9..20	14.9	6..14	9.4
Lilac.....	18..21	16.6	8..15	11.2
Chestnut.....	13..25	17.6	8..16	12.0
Elder.....	14..26	19.7	9..20	13.9
Linden.....	17..29	22.5	12..21	16.4

Evidently the maximum temperatures have no clearer connection with the date of flowering than have the mean daily temperatures.

The sums of temperatures from the beginning of vegetation to the date of flowering have also been computed by different methods and from different initial temperatures. The following are the results when the initial temperature is 0° C.:

Plant.	Sums of positive daily means.	Sums of positive daily maxima.
	° C.	° C.
Narcissus.....	359	591
Lilac.....	613	983
Chestnut.....	771	1,217
Elder.....	990	1,542
Linden.....	1,277	1,938

Here, again, as in previous cases, the relative value of the different methods of taking account of the temperature is determined numerically by taking the sums of the departures from the average for the individual stations and years. In the present case the mean departures as thus determined are exactly the same for both methods, so that four years of observations, 1880–1883, have not sufficed to decide as to which mode of calculation it is proper to adopt as the best. A similar calculation as to the amount of heat received by the lilac and the chestnut between the epochs of leafing and flowering leads to the same indecision as to the methods of calculation. The actual sums between the leafing and the flowering are as follows:

Plant.	Sums of positive daily means.	Sums of positive daily maxima.
	° C.	° C.
Lilac.....	280	433
Chestnut.....	250	372



The flowering and ripening of winter wheat during 1882 and 1883 has been studied on the basis of data from about 500 stations, combined with the previous data for 1880 and 1881.

The mean daily temperature at the time of flowering is for rye  $13.3^{\circ}$ ; but the individual numbers range from  $9^{\circ}$  to  $18^{\circ}$ ; similarly for winter wheat the mean is  $16.2^{\circ}$  and the range from  $10^{\circ}$  to  $21^{\circ}$ . The commencement of vegetation for winter wheat is uniformly adopted as December 1. The sums of the mean daily temperatures have been calculated from several points of departure and seem to prove that the lower limit of useful temperatures is very nearly  $5^{\circ}$  C., so that we can take  $6^{\circ}$  C. as the point of departure, as has been done by many authors.

The sums of the mean daily temperatures, less  $6^{\circ}$  C., rejecting the negative remainders and counting from the 1st of December, are as follows:

Periods for winter grain.	Rye.	Wheat.
	$^{\circ}$ C.	$^{\circ}$ C.
From December 1 to flowering .....	420	586
From December 1 to harvest .....	955	1,099
From flowering to harvest .....	535	503

The harvest date for spring barley is shown to depend in 1882 and 1883 quite as little on the date of sowing as it did in 1881.

The retardation due to altitude is as before, four days per 100 meters. Adopting the 20th of March as an average date of sowing, the sums of the mean daily temperatures have been considered up to the date of harvest, with different assumptions as to the fundamental temperature. As before, the best result is given when the sums are taken of the excess of the mean daily temperatures above  $6^{\circ}$  C., and the resulting figure, 984, is seen to be between the two figures for rye and winter wheat.

In his third memoir Angot (1888) studies the phenomena of 1884 and 1885 in combination with the preceding. The same allowance is made for rates of retardation. The relation between the times of leafing, the mean daily temperature at that date, and the maximum



temperature at that date, is computed by the same process as before, with the following results for the years 1884 and 1885:

Plant.	Daily mean temperature.		Daily maximum temperature.	
	Mean.	Range.	Mean.	Range.
	° C.	° C.	° C.	° C.
Lilac.....	9.1	5.7..14.2	14.7	4.7..20.8
Indian chestnut.....	9.6	6.3..13.7	15.3	10.9..22.8
Birch.....	10.1	5.8..14.3	15.9	9.7..22.7
Oak.....	10.3	3.0..15.1	15.7	11.9..21.0

The mean values here given agree well with those of the previous years, but the individual numbers have such a wide range that we can not conclude any simple relation between the leafing and the mean temperatures.

The relation between the leafing and the sums of temperatures is found, as before, by assuming the end of the last period of frost as the commencement of vegetation; for these years this corresponds with the last few days of January. The useful temperatures are considered to be those above 0° C., and Angot has computed both the sums of the mean daily temperatures and also the sums of the maxima alone with the following results:

Plant.	Sums of daily means.		Sums of daily maxima.	
	1884.	1885.	1884.	1885.
	° C.	° C.	° C.	° C.
Lilac.....	428	414	686	666
Chestnut.....	568	575	924	925
Birch.....	609	587	988	944
Oak.....	709	717	1,149	1,146

The reliability of these sums is, as before, determined by examining the departures, although not according to the strict rules of the law of probabilities of errors, but sufficiently so to show that the uncertainties of each of these figures is larger than the differences for successive years. The average of the two years, 1884 and 1885, are considerably higher than those for the previous four years.

The flowering of the lilac, chestnut, elder, and linden is again investigated by using the observations at some 1,200 stations or less. The reduction for altitude is as before. The mean daily temperatures

and the maximum daily temperatures for the dates of flowering give the results in the following table:

Plant.	Daily mean temperature.		Daily maximum temperature.	
	Mean.	Range.	Mean.	Range.
	° C.	° C.	° C.	° C.
Lilac.....	10.1	4.7..15.4	15.6	9.1..22.0
Chestnut.....	11.7	6.7..17.1	17.9	13.5..26.3
Elder.....	15.3	10.7..19.6	22.2	15.0..29.5
Linden.....	16.3	12.9..20.8	23.0	16.9..29.9

Again the accord with the results of previous years is satisfactory, but the individual variations are so large as to show that there is no clear connection between the epochs of flowering and the mean temperatures. Next the sums of temperatures received by these plants since the last severe cold is computed, assuming 0° C. as the initial temperature, with the following results:

Plant.	Sums of daily mean temperatures.		Sums of daily maximum temperatures.	
	1884.	1885.	1884.	1885.
	° C.	° C.	° C.	° C.
Lilac.....	689	672	1,097	1,070
Chestnut.....	846	841	1,345	1,304
Elder.....	1,063	1,108	1,619	1,685
Linden.....	1,366	1,354	2,091	2,022

These sums agree well among themselves for the two years, but are notably higher than the sums for the four previous years, the excess being so much larger than the uncertainty, as deduced from the agreement of the numbers among themselves, that we can scarcely consider that such sums as these represent the true influence of climate on these plants.

The dates of flowering and harvest of rye and winter wheat at 700 or 800 stations give the following results:

The mean temperatures at the date of flowering are, for rye, in 1884, 14° C., and 1885, 12.2° C.; for winter wheat, in 1884, 15.1° C., in 1885, 16.4° C. These figures agree well with the previous four years, but the individual discrepancies show that there is no simple relation between the flowering of these plants and the mean temperature.

Again, the sums of temperatures are computed from the 1st of December; 5° C. is subtracted from all the mean daily temperatures and the sums of the positive remainders are given. Since in previous years 6° C. has been adopted, whereas the evidence points toward a lower figure, therefore Angot now gives the results of a recomputa-

tion of the five years, adopting  $5^{\circ}$  C. as the lower limit of useful temperatures, with the following results:

*Sums of mean daily temperatures, less  $5^{\circ}$  C. and rejecting negative remainders, from December 1 up to the dates of flowering and of harvesting.*

Year.	Rye.		Winter wheat.	
	Flower-ing.	Harvest-ing.	Flower-ing.	Harvest-ing.
1880 .....	587	1,118	730	1,235
1881 .....	602	1,180	798	1,311
1882 .....	496	1,075	720	1,271
1883 .....	460	1,076	638	1,248
1884 .....	527	1,069	727	1,268
1885 .....	469	1,047	686	1,245
Mean .....	515	1,096	716	1,268

The differences between the numbers for flowering and harvesting show, as in previous years, that although winter wheat requires more heat ( $716^{\circ}$  C.) to bring it up to the flowering point than does rye ( $515^{\circ}$  C.), yet after having attained that point the wheat requires less heat ( $547^{\circ}$  C.) than does the rye ( $581^{\circ}$  C.) in order to ripen the grain to the harvest. This fact, which has shown itself in each of the six years, can be considered as well established.

*The harvest of spring barley.*—The dates of harvest are, as before, reduced to sea level by allowing for retardation at the rate of four days per 100 meters. The sums of mean daily temperatures, less  $5^{\circ}$  C., counting from the 21st of March, which is the mean date of sowing, and up to the date of harvest, are given for each year in the following table:

Year.	Spring barley harvest—sums of temperatures.	Year.	Spring barley harvest—sums of temperatures.
	$^{\circ}$ C.		$^{\circ}$ C.
1880 .....	1,071	1883 .....	1,068
1881 .....	1,110	1884 .....	1,049
1882 .....	1,128	1885 .....	1,042

The general mean for these six years is (within the range of its probable error) the same as the corresponding figures for winter rye.

In a fourth memoir, Angot (1890) gives similar computations for the harvests of 1886 and 1887 in France, the number of stations being now appreciably larger than in the preceding years. A new computation of the retardation due to altitude gives him 3.7 days per 100 meters for the lilac, 4.0 for the chestnut, 3.7 for the elder,

and 3.5 for the oak. For all these he adopts 4 days, as in previous years.

*Leafing.*—The mean temperatures at the dates of leafing for 1886 and 1887 are given, as follows:

*Data for 1886 and 1887.*

Plant.	Mean of daily temperature.	Mean of daily maximum temperature.	Plant.	Mean of daily temperature.	Mean of daily maximum temperature.
	° C.	° C.		° C.	° C.
Lilac .....	9.4	14.8	Birch .....	9.9	15.3
Chestnut.....	10.6	16.2	Oak.....	11.7	17.6

The sums of temperatures received by these plants from the last freezing period up to the time of leafing, and counting from 0° C. as the initial temperature, are as follows:

Plant.	Sums of daily means.		Sums of daily maxima.	
	1886.	1887.	1886.	1887.
	° C.	° C.	° C.	° C.
Lilac.....	356	402	622	772
Chestnut.....	469	531	738	933
Birch.....	465	531	796	961
Oak.....	622	682	1,016	1,208

*The flowering of the lilac, chestnut, elder, and linden.*—A new determination of the rate of retardation of flowering for these plants gives 4.7, 4.2, 4.4, and 3.8 days per 100 meters, respectively, for which, as before, 4 days is adopted. The mean temperatures at the times of flowering for the years 1886 and 1887 are as follows:

Plant.	Daily means.	Daily maxima.
	° C.	° C.
Lilac.....	12.2	17.8
Chestnut.....	12.8	18.7
Elder.....	15.2	21.0
Linden.....	16.4	22.5

The sums of temperatures above 6° C., counting from the last freezing period and up to the date of flowering, for the years 1886 and 1887 are as follows:

Plant.	Sums of daily means.		Sums of daily maxima.	
	1886.	1887.	1886.	1887.
	° C.	° C.	° C.	° C.
Lilac.....	621	661	1,020	1,184
Chestnut.....	704	773	1,147	1,351
Elder.....	975	1,001	1,543	1,682
Linden.....	1,269	1,245	1,949	2,014

The probable errors of these sums, considered individually, are quite large, and their agreement from year to year is not sufficient to justify the belief that we have attained to a satisfactory expression for the connection between the temperature and the date of flowering.

*Flowering of rye and winter wheat—Harvest of rye, winter wheat, and spring barley.*—A new investigation, based on an increased number of stations for the years 1886 and 1887, gives for the rate of retardation of these epochs the following figures: Flowering of rye, 4.2 days per 100 meters; flowering of winter wheat, 4; harvest of rye, 4.5; harvest of winter wheat, 4.3; harvest of spring barley, 4.2. We can, therefore, as before, take 4 days as an approximate value for all these phenomena.

The mean temperature at the time of flowering is determined, both for daily means and for daily maxima, as follows:

Flowering of plant.	Daily mean.		Daily maxima.	
	1886.	1887.	1886.	1887.
	° C.	° C.	° C.	° C.
Rye.....	15.4	12.3	22.1	18.8
Wheat.....	16.2	17.3	22.0	24.3

Again, the average numbers agree well from year to year, but the individuals from which they are derived have a wide range.

The sums of the mean daily temperatures, less 5° C., counting from December 1 for the winter rye and wheat, but from March 21, for the spring barley, are as follows:

*Sums of temperature.*

Plant and stage.	1886.	1887.	Average.
	° C.	° C.	° C.
Flowering of rye.....	313	415	364
Flowering of winter wheat.....	735	630	682
Harvest of rye.....	1,080	1,017	1,048
Harvest of winter wheat.....	1,286	1,185	1,236
Harvest of spring barley.....	1,214	1,120	1,167

From the flowering to the harvest, on the average of these two years, rye has received  $1,048 - 364 = 684^{\circ}$  C., and winter wheat  $1,236 - 682 = 554^{\circ}$  C., but on the average of eight years, 1880–1887, the sums of temperatures, less 5° C., have been, for rye, from December 1 to the flowering,  $477^{\circ}$  C., and from flowering to harvest,  $607^{\circ}$  C.; for winter wheat the numbers are, respectively,  $708^{\circ}$  to  $549^{\circ}$  C. From the beginning of vegetation up to harvest the numbers are: For rye,  $1,084^{\circ}$  C.; winter wheat,  $1,256^{\circ}$  C.; spring barley,  $1,103^{\circ}$  C. These results can be considered as having definitely established the fact that

in France rye requires less heat to bring it to the harvest and winter wheat more; but, on the other hand, from the flowering to the harvest rye requires more and winter wheat less.

The following table gives a résumé of Angot's general average dates and temperatures for sea level for the whole of France for the years 1880-1887:

Plant.	Mean daily temperature when—	
	Leafing occurs.	Flowering occurs.
	° C.	° C.
Lilac.....	9.1	11.2
Indian chestnut.....	10.1	14.6
Birch.....	10.4	.....
Oak.....	11.1	.....
Elder.....	.....	17.1
Linden.....	.....	18.9
Rye.....	.....	18.4
Winter wheat.....	.....	18.2

As to the sums of the mean daily temperatures above 5° C., counting from December 1:

Plant.	Sums of temperature at time of—	
	Flowering.	Harvest.
	° C.	° C.
Rye.....	477	1,065
Winter wheat.....	707	1,256

The harvest of spring barley occurs when the sum of the mean daily temperatures, less 5° C. and counting from March 21 or the average date of sowing, amounts to 1,102° C.

The large variations of the individual numbers whose means are given above are probably due to special meteorological conditions, and Angot states that he will report upon these if it is possible to take them into account when ten whole years of observations have accumulated.

#### REQUESTS FOR PHENOLOGICAL OBSERVATIONS.

The influence of a climate upon cultivated crops is parallel to its influence upon uncultivated plants, and the comparative study of climates in their relations to plants can be attained by careful observations of the general features of the natural life of special plants that are widely distributed over the earth. To this end several special invitations have been issued urging the observation of certain phenological stages.

(A) Hoffmann and Ihne have published a special list of plants selected by them as a result of many years' experience in Europe. The following calendar, copied from the appeal for "phenological observations," contained in their "Beitrage, 1884," shows the names of the plants and the approximate date in Europe of the phenomena that they wish to have observed. Corresponding observations in America are desirable and should be communicated either to them directly or to the journals of botany, climatology, or general science, or to the botanist of the Department of Agriculture.

#### CALENDAR FOR PHENOLOGICAL OBSERVATIONS.

*Instructions.*—Plants should be examined daily. The object is to obtain for individual stations average data characteristic of the climate; therefore plants that are known to be exceptionally early or late, and those that are forced by special treatment, or those that are artificially trained on walls are not to be considered. It is not necessary to confine the observations to the same plant year after year, but to those individuals that represent the average conditions of the plant in nature.

For brevity the following notation may be used:

(P) Pollen disseminated (*Pollen effunditur*. Linne).

(1) Leaf, or the first visible surfaces of the leaves, or beginning of the leafing out or of the foliage (*frondescentia: prima folia explicantur* Linne; *erste Blattoberfläche* Hoffmann; *feuillaison* Quetelet).

(F) Full foliage: All leaves have appeared (*folatio perf.* Linne; *allgemeine Blatt* Hoffmann).

(2) Flower, or the first opening of the flower buds (*efflorescentia: primi flores ostenduntur* Linne; *erste Blüthe offen* Hoffmann; *floraison* Quetelet).

(3) Ripe fruit (*Prima fructus matura; baccæ definite coloratæ* Linne; *erste Frucht reif* Hoffmann; *maturation des fruits* Quetelet).

(H) Harvest, or first date of cutting cereals (*Ernte Anfang* Hoffmann; *Messis initium* Linne).

(4) Leaves color or fall (*foliorum pars major decolorata* Linne); *allgemeine Laubverfärbung* Hoffmann; *vollständige Entlaubung* Karl Fritsch; *Effeuillaison, chute des feuilles* Quetelet).



*Phenological calendar for Giessen.*

[Lat. 50° 35' N. ; long. 8° 12' east of Greenwich ; altitude, 160 meters.]

Date.	Plant.	Phase of vegetation.	Date.	Plant.	Phase of vegetation.
Feb. 10	<i>Corylus avellana</i> .....	Pollen.	May 28	<i>Atropa belladonna</i> .....	Flower.
Apr. 10	<i>Æsculus hippocast.</i> ...	Leaf.	June 1	<i>Symphoricarpos racemosa.</i>	Do.
18	<i>Ribes rubrum</i> .....	Flower.	2	<i>Rubus idæus</i> .....	Do.
17	<i>Ribes aureum</i> .....	Do.	2	<i>Salva officinalis</i> .....	Do.
17	<i>Betula alba</i> .....	Pollen.	5	<i>Cornus sanguinea</i> .....	Do.
18	<i>Prunus avium</i> .....	Flower.	14	<i>Vitis vinifera</i> .....	Do.
19	<i>Prunus spinosa</i> .....	Do.	20	<i>Ribes rubrum</i> .....	Fruit.
19	<i>Betula alba</i> .....	Leaf.	21	<i>Ligustrum vulgare</i> ...	Flower.
22	<i>Prunus cerasus</i> .....	Flower.	22	<i>Tilia grandifolia</i> .....	Do.
23	<i>Prunus padus</i> .....	Do.	26	<i>Lonicera tatarica</i> .....	Fruit.
23	<i>Pyrus communis</i> .....	Do.	30	<i>Lilium candidum</i> .....	Flower.
25	<i>Fagus sylvatica</i> .....	Leaf.	July 4	<i>Rubus idæus</i> .....	Fruit.
28	<i>Pyrus malus</i> .....	Flower.	5	<i>Ribes aureum</i> .....	Do.
May 1	<i>Quercus pedunculata</i> ..	Leaf.	19	<i>Secale cereale hibern.</i> ..	Harvest.
3	<i>Lonicera tatarica</i> .....	Flower.	30	<i>Sorbus aucuparia</i> .....	Fruit.
4	<i>Syringa vulgaris</i> .....	Do.	30	<i>Symphoricarpos racemosa.</i>	Do.
4	<i>Fagus silv.</i> .....	Full foliage.	Aug. 1	<i>Atropa belladonna</i> .....	Do.
4	<i>Narcissus poeticus</i> ....	Flower.	11	<i>Sambucus nigra</i> .....	Do.
7	<i>Æsculus hippocast.</i> ...	Do.	24	<i>Cornus sanguinea</i> .....	Do.
9	<i>Cratagus oxyacantha</i> ..	Do.	Sept. 9	<i>Ligustrum vulgare</i> .....	Do.
12	<i>Spartium scoparium</i> ..	Do.	16	<i>Æsculus hippocast.</i> ...	Do.
14	<i>Quercus pedunculata</i> ..	Foliage.	Oct. 10	.....do.....	Fall.
14	<i>Cytisus laburnum</i> .....	Flower.	13	<i>Betula alba</i> .....	Do.
16	<i>Cydonia vulgaris</i> .....	Do.	15	<i>Fagus sylvatica</i> .....	Do.
16	<i>Sorbus aucuparia</i> .....	Do.	20	<i>Quercus pedunculata</i> ..	Do.
28	<i>Sambucus nigra</i> .....	Do.			
28	<i>Secale cereale hibern.</i> ..	Do.			

(B) *Smithsonian list*.—In the United States calls for phenological observations were issued by the New York Agricultural Society in 1807 and by the Regents of the University of New York about 1820, also by Josiah Meigs as Commissioner of the General Land Office in 1817, but the principal work has been that undertaken by Prof. Joseph Henry, who as Secretary of the Smithsonian Institution established in 1848 a system of phenological observations undoubtedly arranged by Dr. Asa Gray or Dr. Arnold Guyot, and subsequently published a revised list of plants and epochs.

This system was also promulgated by the Department of the Interior on behalf of the Patent Office and its Bureau of Agriculture requesting accurate observations. The following is an abstract of Doctor Gray's schedule, which is here produced, because we shall have occasion to quote observations made on this plan, which was a slight modification of Quetelet's plan.

The observations thus collected by the Smithsonian, 1854–1859, were used by Fritsch in his memoir and list quoted on page 191.

The following observations were requested by the Smithsonian Institution:

(1) Frondescence, or leafing: When the buds first open and exhibit the green leaf.

(2) Flowering: When the anther is first exhibited—(a) in the most favorable location; (b) general flowering of the species.

(3) Fructification: When the pericarp splits spontaneously in dehiscent fruits or the indehiscent fruit is fully ripe.

(4) Fall or leaf: When the leaves have nearly all fallen.

*List of plants recommended for observation by the Smithsonian Institution.*

Pages of Gray's Man- ual of Botany.		Genera.	Common names.
Edition VI.	Edition V.		
118	119	<i>Acer rubrum</i> L.....	Red or soft maple.
117	119	<i>Acer dasycarpum</i> Ehrh.....	White or silver maple.
117	119	<i>Acer saccharinum</i> L.....	Sugar maple.
289	285	<i>Achillea millefolium</i> L.....	Millefoil or yarrow.
48	47	<i>Actea rubra</i> Willd.....	Red baneberry.
48	47	<i>Actea alba</i> Bigelow.....	White baneberry; necklace weed.
116	118	<i>Aesculus hippocastanum</i> L.....	Horse-chestnut.
116	118	<i>Aesculus glabra</i> Willd.....	Ohio buckeye.
116	118	<i>Aesculus flava</i> Ait.....	Yellow buckeye.
107	110	<i>Ailantus glandulosa</i> .....	Tree of heaven; allanthus.
166	162	<i>Amelanchier canadensis</i> .....	Shad bush; service berry.
182	180	<i>Amorpha fruticosa</i> L.....	False indigo.
		<i>Amygdalus nana</i> L. <sup>a</sup> .....	Flowering almond.
88	88	<i>Anemone nemorosa</i> L.....	Wind flower; wood anemone.
46	45	<i>Aquilegia canadensis</i> L.....	Wild columbine.
315	292	<i>Arctostaphylos uva-ursa</i> (Spreng).....	Bearberry.
341	305	<i>Asclepias cornuti</i> Decaisne.....	Milkweed.
50	50	<i>Asimina triloba</i> Dunal.....	Papaw.
320	299	<i>Azalea nudiflora</i> L.....	Common red honeysuckle.
398	321	<i>Bignonia (Tecoma) radicans</i> (Juss).....	Trumpet creeper.
479	455	<i>Castanea vesca</i> L.....	Chestnut.
468	448	<i>Carya alba</i> .....	Shagbark or shellbark hickory.
147	144	<i>Cercis canadensis</i> L.....	Redbud; Judas tree.
152	148	<i>Cerasus virginiana</i> D. C.....	Chokeberry or chokecherry.
152	149	<i>Cerasus serotina</i> D. C.....	Wild black cherry.
387	401	<i>Chionanthus virginica</i> L.....	Fringe tree.
47	48	<i>Cimicifuga racemosa</i> Ell.....	Black-snake root; rattlesnake root.
91	98	<i>Claytonia virginica</i> L.....	Spring beauty.
322	297	<i>Clethra alnifolia</i> .....	White alder or sweet pepper bush.
214	200	<i>Cornus florida</i> L.....	Flowering dogwood. (The real flower, not the white involucre.)
166	160	<i>Crataegus crus-galli</i> L.....	Cockspur thorn.
166	160	<i>Crataegus coccinea</i> L.....	Scarlet-fruited thorn.
166	159	<i>Crataegus oxycantha</i> L.....	English hawthorn.
315	298	<i>Epigaea repens</i> L.....	Trailing arbutus; ground laurel.
188	177	<i>Epilobium angustifolium</i> L.....	Willow herb.
528	538	<i>Erythronium americanum</i> Smith.....	Dogtooth violet or adder's-tongue.
385	401	<i>Fraxinus americana</i> L.....	White ash.
311	289	<i>Gaylussacia resinosa</i> Torrey and Gray.	Black huckleberry.
389	385	<i>Gerardia flava</i> L.....	Yellow false foxglove.
108	107	<i>Geranium maculatum</i> L.....	Crane's bill.

<sup>a</sup> This genus of Rosaceae is not in Gray's Manual of Plants Indigenous to United States.

*List of plants recommended for observation by the Smithsonian Institution—Con.*

Pages of Gray's Man- ual of Botany.		Genera.	Common names.
Edition VI.	Edition V.		
334	810	<i>Halesia tetraptera</i> Willd.....	Snowdrop tree.
88	88	<i>Hepatica triloba</i> Chaix.....	Round-lobed liverwort.
223	213	<i>Houstonia cærulea</i> Hook.....	Bluets; innocence, etc.
94	85	<i>Hypericum perforatum</i> L.....	St. John's wort.
513	516	<i>Iris versicolor</i> L.....	Large blue flag.
819	298	<i>Kalmia latifolia</i> L.....	Mountain laurel.
447	423	<i>Laurus benzoin</i> L ( <i>Benzoin odoriferum</i> Nees.)	Spice bush; Benjamin bush.
289	265	<i>Leucanthemum vulgare</i> Lam.....	Ox-eye daisy; white weed.
219	202	<i>Linnaea borealis</i> (Gronov) (Linnæus)...	Twin flower.
306	283	<i>Lobelia cardinalis</i> L.....	Red cardinal flower.
220	203	<i>Lonicera tartarica</i> L.....	Foreign spurs.
128	126	<i>Lupinus perennis</i> L.....	Wild lupine.
50	50	<i>Liriodendron tulipifera</i> L.....	Tulip tree; American poplar.
49	49	<i>Magnolia glauca</i> L.....	Small or laurel magnolia; sweet bay.
225	211	<i>Mitchella repens</i> L.....	Partridge berry.
464	444	<i>Morus rubra</i> L.....	Red mulberry.
55	56	<i>Nymphaea odorata</i> Ait.....	Sweet-scented water lily.
		<i>Persica vulgaris</i> L. <sup>a</sup> .....	Peach.
53	54	<i>Podophyllum peltatum</i> L.....	Mandrake; May apple.
536	545	<i>Pontederia cordata</i> L.....	Pickereel weed.
506	507	<i>Pogonia ophioglossoides</i> Nutt.....	Adder's-tongue.
164	161	<i>Pyrus communis</i> L.....	Common pear tree.
164	161	<i>Pyrus malus</i> L.....	Common apple tree.
475	450	<i>Quercus alba</i> L.....	White oak.
821	800	<i>Rhododendron maximum</i> L.....	Great laurel.
176	165	<i>Ribes rubrum</i> L.....	Red currant.
134	131	<i>Robinia pseud-acacia</i> L.....	Common locust.
134	131	<i>Robinia viscosa</i> Vent.....	Clammy locust.
155	157	<i>Rubus villosus</i> Ait.....	Blackberry.
217	205	<i>Sambucus canadensis</i> L.....	Common elder.
217	205	<i>Sambucus nigra</i> L.....	Black elder.
58	60	<i>Sanguinaria canadensis</i> L.....	Bloodroot.
57	58	<i>Sarracenia purpurea</i> L.....	Side-saddle flower.
170	168	<i>Saxifraga virginiana</i> Michx.....	Early saxifrage.
528	530	<i>Smilacina bifolia</i> Ker. ( <i>Maianthemum</i> <i>canadense</i> Gray.)	Two-leaved Solomon-seal.
174	166	<i>Syringa vulgaris</i> L. ( <i>Philadelphus</i> <i>coronarius</i> Gray.)	Lilac.
303	280	<i>Taraxacum dens-leonis</i> Desf.....	Dandelion.
101	103	<i>Tilia americana</i> L.....	Bass wood; American lime or linden.
462	442	<i>Ulmus americana</i> L.....	American elm.
219	206	<i>Viburnum lentago</i> L.....	Sweet viburnum.

<sup>a</sup> This genus of the order Rosaceæ is not in Gray's Manual of Plants Indigenous to the United States.

## Chapter XI.

### ACCLIMATIZATION AND HEREDITY.

Scientific literature is full of illustrations of the natural and artificial acclimatization of plants and the influence of the annual variations of climate on the crops, all of which exemplify Linsser's general laws.

#### GRAPEVINE.

The following remarks and data relative to the changes of climate during the historical period, as given by Fritz (1889, pp. 266-269), will be valuable for further study and are referred to in another part of this work:

The northern boundary of vine culture in Europe extends from somewhat north of the mouth of the Loire, where the Marne empties into the Seine, to the junction of the Aar and the Rhine, north of the Erzgebirge, to about the fifty-second degree of latitude, descends along the Carpathians to the forty-ninth degree, extends on this parallel eastward, and near the Volga turns southward to its mouth, on the Caspian Sea. In the middle ages wine was made in the south of England, in Gloucester and Windsor; in the Netherlands; in Namur, Liege, Louvain; in northern Germany, in the Eifel range of hills in Sauerland (a division of Rhenish Prussia), on the slopes of the Ruhr Mountains, on the Weser as far as Raddesdorf, in lesser Waldeck (or Pyrmont); in Hesse as far as Fritzlar; in Thuringia, in Brandenburg, and in lower Lusatia; in Berlin, Brandenburg, Oderberg, Guben; in Prussia, at Kulm, Neuenburg, Thorn, Marienburg, even beyond Königsberg; in Kurland (Courland), and even in Seeland (Zealand) the vine has been cultivated in great quantities. Although we have very favorable accounts of many harvests in those times, even for the highest of the latitudes mentioned above, still one must not generalize too far. The sensation of taste is very variable and often peculiar. We frequently at the present time obtain a very sour beverage from countries reputed to produce good wine, and in the north we eat grapes which farther south are considered very sour. It must be taken for granted that in those times when there was no communication over long distances they were not very exacting in regard to wine, particularly as the best wines were unknown, as must have been the case in northern Germany, the Netherlands, and England. If the wine was harsh and sour, it was still wine, which in favorable years, and even in those latitudes where the crop did excellently well, could be made into a very drinkable beverage. In later times, and when better wines became known, when

the culture of the vine was carried to greater perfection in southern Germany and wine could more easily be carried into northern Germany, the cultivation of the vine must have been given up in regions where favorable years were only the exception. When the first decade of the nineteenth century proved very unfavorable to vine cultivation, a number of vineyards were suppressed even in the best situations, such as Rhenish Hesse and Rheingau, which were afterwards restored with the return of better times, namely, after 1834 and 1835. With the present facilities for communication and the competition in the wine business resulting therefrom vine culture is no longer profitable in many places where thirty years ago it was so; in many places even grain cultivation is declining, because the grain can be procured from a distance cheaper than the cost of cultivation, as is especially the case in Alpine countries. No one would conclude that this is owing to the deterioration of the climate, and with equal right one can not attribute the decline of vine culture in high latitudes, where it is now no longer profitable, to change of climate.

Herodotus describes the fertility of Assyria, notwithstanding that it seldom rains there. No one, he says, could bring himself to believe in its productiveness who was not convinced of it by seeing for himself. At present the fruitfulness of that region is very limited. But Herodotus also describes the excellent irrigation of that country in his time, and Alexander the Great is said to have found on the Scythian frontier an inscription dedicated to Semiramis (2000 B. C.): "I forced the streams to flow where I willed, and I willed only what was useful; I made the dry earth fruitful by watering it with my streams." At the present day the countries in question produce only very meager crops, with the exception of the regions on the Tigris, near Bagdad; in Mesopotamia, near Urfa; in northern Syria, near Aintab, and Messir and other places, where recently irrigation canals have again been laid and magnificent cultivation thereby revived. No change of climate has taken place; human energy alone has altered. Similar changes are seen in Palestine, in Arabia, in Sicily, and many other countries. Should the Chinese in many portions of their country neglect irrigation for even short periods they would quickly see only deserts where now garden cultivation reigns, while the climate would not change in the least. No one acquainted with the true cause would attribute to change of climate the increased productiveness of Lombardy since the restoration of its excellent system of canals and irrigation, or the great decrease of grain culture in Switzerland. Without this knowledge only perverted and false conclusions would be derived.

The diminution of forests in the extreme north of Europe, in Iceland, and in the high Alpine regions is more simply to be explained by the partial deforestation done by the hand of man, rendering the remainder sparser and less capable of resistance to wind and weather than by hypothesis of change of climatic conditions.

At the same time it will not be denied that by irrigation and drainage, by important changes in the system of cultivation, by various natural phenomena of nature, etc., many changes of a climatic character take place. These changes, however, are only local and disappear as soon as the causes which produced them are removed.

Besides, there is in climatic conditions only a moderate stability,

subject to steady and in all probability periodic variations and interchanges, which are difficult to recognize in consequence of the manifold combinations of the numerous effective factors. Climatic changes, extending over long periods of time, are indicated by geological periods, which latter themselves demonstrate again only the gradual and not any sudden alterations of climate. Sudden, and even very moderate slow changes of climate cause the destruction of the vital organism.

The comparison of the climatic conditions of individual years, the differences in the yield of fruits of various kinds, as already mentioned above, the unfavorable years in central Europe at the end of the sixteenth and eighteenth and beginning of the nineteenth centuries, and the very favorable seasons for grain and wine in the last quarter of the seventeenth and at the beginning of the eighteenth century and in the first third of the nineteenth century, together with the recurring failure under similar conditions of crops, particularly of wine, in 1847 and 1881, caused by the cool weather at the end of summer and beginning of autumn, in spite of the hot summer which had preceded it, etc., and furthermore the exact numerical researches based on results of observations of the meteorological elements, all show a variability of climate such as is accomplished within a century, or even within the lifetime of a man, and which can be most positively recognized from year to year, from decade to decade. To find the causes of these changes belongs to those who have devoted themselves to researches in the laws of meteorology, and particularly to discovering the methods by which to prognosticate the conditions of weather for long periods in advance.

*Distribution of good and poor wine crops, by decades, since 1600.*

[From Fritz (1889), p. 301.]

Decade.	Germany (Rhine).		Switzerland (Zurich).		Decade.	Germany (Rhine).		Switzerland (Zurich).	
	Above aver- age.	Below aver- age.	Above aver- age.	Below aver- age.		Above aver- age.	Below aver- age.	Above aver- age.	Below aver- age.
1600-1609.....			1	9	1760-1769.....	4	6	5	5
1610-1619.....			4	6	1770-1779.....	5	5	7	3
1620-1629.....			2	8	1780-1789.....	5	5	8	2
1630-1639.....			4	6	1790-1799.....	2	8	8	2
1640-1649.....	1	9	2	8	1800-1809.....	5	5	5	5
1650-1659.....	2	8	3	7	1810-1819.....	4	6	2	8
1660-1669.....	2	8	5	5	1820-1829.....	4	6	6	4
1670-1679.....	3	7	5	5	1830-1839.....	6	4	5	5
1680-1689.....	4	6	7	3	1840-1849.....	3	7	6	4
1690-1699.....	3	7	1	9	1850-1859.....	4	6	4	6
1700-1709.....	5	5	6	4	1860-1869.....	4	6	6	4
1710-1719.....	5	5	4	6	1870-1879.....	4	6	2	8
1720-1729.....	6	4	9	6	1880-1887.....	2	6	2	6
1730-1739.....	3	7	5	5	General average.	3.9	6.0	4.5	5.4
1740-1749.....	6	4	3	7					
1750-1759.....	5	5	5	5					

*Good and poor wine crops, by years, since 1820.*

[From Fritz (1889), pp. 293, 295, 296.]

Year.	Prussia (in Elmers, per morgen).	France (Volnay) (in hectoliters per hectare).	Hochberg, Baden (hectoliters per hectare).	Nikita, Crimea (hectoliters per hectare).	Hesse (hectoliters per hectare).	Ohio (gallons per acre).	Year.	Prussia (in Elmers, per morgen).	France (Volnay) (in hectoliters per hectare).	Hochberg, Baden (hectoliters per hectare).	Nikita, Crimea (hectoliters per hectare).	Principality of Hesse.	Ohio (gallons per acre).
1820.....	2.03	7					1854.....	1.93	2	2			
1821.....	0.69	7					1855.....	3.82	7	4			
1822.....	11.19	16	34				1856.....	8.13	8	3			
1823.....	5.70	7	56				1857.....	9.95	22	4			
1824.....	5.35	7	14				1858.....	10.75	26	64	12.88		
1825.....	8.20	6	55				1859.....	9.07	17	27	12.88		
1826.....	15.65	32	92				1860.....	5.94	10	12	18.17		
1827.....	4.55	22	1				1861.....	4.62	6	6	8.78		
1828.....	16.45	29	52				1862.....	8.92	15		9.66		
1829.....	5.16	16	33				1863.....	7.14	17		9.06		
1830.....	0.80	5	4				1864.....	5.40	15		11.00	18.7	
1831.....	3.67	8					1865.....		17		6.10	28.0	41.8
1832.....	5.28	10	26				1866.....		13		13.21	44.8	21.4
1833.....	10.95	19	55				1867.....		16		15.23	23.4	39.8
1834.....	15.43	29	45				1868.....		27		24.59	46.5	19.1
1835.....	12.65	33	55				1869.....		15		28.99	31.7	14.9
1836.....		18	28				1870.....		18		18.76	23.6	236.7
1837.....	4.51	20	14				1871.....		17		16.46	8.8	91.7
1838.....	2.74	12	13				1872.....		7			8.7	24.4
1839.....	7.06	17	18				1873.....		7			10.0	10.7
1840.....	4.24	19	35				1874.....		15			32.4	106.9
1841.....	3.25	6	2				1875.....		27			51.8	24.6
1842.....	8.05	17	24				1876.....		15			27.8	63.8
1843.....	2.83	9	15				1877.....		10			19.8	59.1
1844.....	3.93	9	11				1878.....		10			31.2	80.0
1845.....	5.36	9					1879.....		3			9.8	90.3
1846.....	13.53	21	23				1880.....		2			3.9	126.0
1847.....	10.09	22	45				1881.....		22			36.7	88.0
1848.....	7.95	22	32				1882.....		12			13.5	121.0
1849.....	6.90	13	19				1883.....		8			33.3	23.0
1850.....	6.68	11	23				1884.....		19				
1851.....	5.57	11	13				1885.....		10				
1852.....	7.64	13	15				1886.....		4				
1853.....	7.07	10	34				1887.....		11				



*Wheat crop in Ohio, by years, since 1850.*

[From Fritz (1889), p. 303. The figures for 1850-1877 refer to the average of two counties, viz, Belmont in the southeast and Erie on the north border of the State. The figures for 1878-1883 are averages for the whole State.]

	Bushels per acre.		Bushels per acre.		Bushels per acre.
1850.....	17.0	1862.....	13.8	1874.....	17.8
1851.....	14.7	1863.....	12.8	1875.....	13.8
1852.....	14.6	1864.....	6.7	1876.....	14.5
1853.....	11.8	1865.....	6.8	1877.....	11.6
1854.....	9.1	1866.....	10.5	1878.....	16.9
1855.....	15.6	1867.....	13.0	1879.....	17.7
1856.....	11.4	1868.....	12.9	1880.....	17.1
1857.....	10.7	1869.....		1881.....	13.8
1858.....	9.7	1870.....		1882.....	15.6
1859.....	17.0	1871.....	14.3	1883.....	16.6
1860.....	13.8	1872.....	8.5		
1861.....	13.4	1873.....	14.4		

**GRASSES.**

Relative to the acclimatization of the grasses Spörer (1867) says:

As in the Alps and Himalayas up to altitudes of 15,000 to 16,000 feet, so also in the farthest north, beyond the limit of trees, the grasses flourish. The varieties that compose the grassy carpet of Taimyr are still somewhat numerous. They embrace 10 families and 21 species; about one-half belong to the sour-grass family, the binse or rushes, ried (reed), woold or cotton grass. But fully one-half are the sweet grasses, such as in central Europe are esteemed the best fodder, and not less so in Taimyr Land, where they extend to the shores of the icy Arctic Ocean beyond latitude 75° 30' north, including among them the "wiesen" or meadow grass, the rispen or ray grass (*Poa pratensis*), and the "rasen schmiele" or turfy hair grass, *Aira deschampsia cæspitosa*. It is not surprising, therefore, that the best milch cattle, the so-called "cholgogor breed," the successors of the cattle transported thither from the Netherlands by the care of Peter the Great, should flourish in the desert polar regions at Mesenja.

The sour grasses, as genuine early spring plants, form their flowers in the previous summer season, and at the beginning of the northern summer (July 10 to 20) are in the fullest bloom and have already turned brown when the sweet grasses begin to show their flower buds.

In general the ground thaws only to the depth of a few inches and the roots do not penetrate into the frozen soil. The tundra of northern Russia and Siberia rests on such a frozen soil; the steppe or prairie or llano rests on unfrozen, deeper, and dryer soil.

The modest circle of plants that surrounds our Arctic Circle is not so complexly constituted under different longitudes as are those of the warmer phenological girdles of the globe; everywhere we have the same species of plants and the same families; everywhere the gramineæ, the cruciferæ, the caryophylleæ, and the saxifragaceæ, are the dominating families, and among the genera the *Draba Saxifraga*, *Ranunculus*, *Carex*, and the meadow grasses; all these

high northern varieties are enduring; only a few of them fail annually to set their fruit and ripen their seed. An annual plant disappears when for a single season it fails to ripen its seed.

A comparison of the flora of Spitzbergen and the high portions of the Alps and Pyrenees shows that the former are the lost children of European flowers that have since the Glacial epoch survived at great altitudes in the mountains as well as in the damp, cold morasses of central Europe.

A comparison of the flora of Taimyr and the mountains of southern Siberia shows that the northern flora has wandered thither and become acclimatized from the southern, and that this process is still going on.

### CEREALS.

The elaborate report of Brewer on cereals, in the Tenth Census of the United States, contains the fullest information as to the relation of climate and soil to our cereals. From pages 10 to 27 of this volume I quote the following general remarks:

We may say that, as a rule, in all former times, and until modern means of transportation came into use, the grain most largely consumed for bread in any country or region was the one most easily and most surely grown at home, or at least at no great distance away; the bread, of necessity, had to be made of such grain as could be grown or procured with the facilities then enjoyed. Rye, buckwheat, oats, barley, and millet had among our ancestors an importance as bread plants that they have now lost and will probably never regain. This fact, apparently so obvious and yet so hard to realize in practice, lies at the bottom of that agricultural revolution already alluded to, which is now going on everywhere among nations and peoples of our civilization, and most notably in western Europe.

Seven species (calling buckwheat a cereal) are cultivated in America in sufficient abundance to be returned in the census tables, and three or four more are occasionally cultivated in a few localities. Taken altogether, these include all the more important cereals of the world.

Of the seven species we have to deal with, six are natives of the Eastern Hemisphere and one of the western. No cultivated grain has originated on an island, if we except canary grass, and none in southern Africa or Australia, regions otherwise very rich, botanically, in species. Humboldt called it a striking phenomenon "to find on one side of our planet nations to whom flour and meal from small-eared grasses, and the use of milk, were completely unknown; while the nations of almost all parts of the other hemisphere cultivated the cereals and reared milk-yielding animals. The culture of the different kinds of grasses may be said to afford a characteristic distinction between the two parts of the world."

The genera to which the principal cereals belong are: *Oryza*, or rice; *Triticum*, which includes all the varieties of wheat and spelt; *Avena*, oats of various kinds; *Hordeum*, the various kinds of barley; *Secale*, rye, and *Zea*, Indian corn. Among the true cereals—that is, belonging to the grass family—there are various species of millet, belonging to several different genera (*Panicum*, *Pennisetum*, *Emilium*, *Setaria*, *Holcus*, and *Sorghum*); durra, a species of *Sorghum*

(called also Indian millet and Guinea corn, and spelled in various ways, as "dura," "dhura," "doura"); canary grass, *Phalaris*, and a few other species belonging to the grasses. In addition to these botanical cereals are the buckwheats, which, for convenience in this report, are classed among the true cereals. They belong to the genus *Polygonum*, two species of which are cultivated in this country, and perhaps others elsewhere. Several species belonging to the genus *Chenopodium* have been cultivated in various parts of the world, particularly in India and central Asia, but none are of importance to European nations as grains. Of a considerable list that might be made, wheat, rice, and Indian corn are the first three in importance; oats, barley, and rye next; then durra, the millets, and buckwheats next; all the remainder being of insignificant importance to the world at large.

However defined and classified, and however used, all the cereals are agricultural grains, all are starchy, all are breadstuffs, and all are annual plants.

Being annuals, they are adapted to almost universal cultivation where the summer climate admits, for "an annual plant may be said to belong to no country in particular, because it completes its existence during the summer months, and in every part of the world there is a summer."

This fact underlies the agricultural importance of the cereals. Every gardener knows that annuals may be brought from almost any country and be made to flourish in cultivation in any other country in which they can complete their life in one summer, and that, even if the summer is too short, varieties may be produced by art which will mature quicker, and then their cultivation may be extended to climates unlike that of their original home. This may be continued up to certain limits set by nature for each species, which limits can be determined only by experiment. Not so with perennials. They must have not only a favorable summer climate, but also a favorable winter climate and a favorable average climate, and, moreover, be able to stand occasional wide deviations from the average climate. The exceptional heat of one year or cold of another, a too wet season or a too dry one, may kill the tree or perennial which has lived and thrived for many years. Hence all perennials are restricted in their growth to very much narrower limits than annuals. Moreover, annual plants are believed to be much more variable under different external conditions than perennials are. They vary more in nature, and it is among the cultivated annual species that we have the widest variation known to science. They can adapt themselves more readily to changes of soil, climate, and other variable conditions than perennials. Thus it is that the plains of Dakota and Manitoba, with their genial summers and fertile soil, even though the winters be of Arctic severity, and California, with its rainless summer, but genial winter, can alike send wheat to the mild-wintered and moist-summered British islands.

Illustrating the first point regarding excellence of seed, both as to its actual condition and its pedigree, there are numerous illustrations recorded; but the famous experiments of Mr. Frederick Hallett, of Brighton, England, may be taken as a good illustration. The experiments were planned with so much intelligence, conducted with such

patience and care, were so profitable in their results—the essential results have been confirmed in so many other ways and by so many practical men—that they are worthy of being quoted in this connection.

He began with a single head of wheat, chosen irrespective of size or vigor, but of a variety producing a good quality of grain. The head was  $4\frac{3}{4}$  inches long and had 47 grains, which were carefully planted in rows, 1 grain in a place, 12 inches apart each way. At harvest the plants were carefully compared, and the one with the largest number of heads was chosen, and the grains from the best head of this best plant were planted the next year in the same way; and this was continued year after year, choosing each time for seed the best head from the most prolific plant. At the first harvest the best plant bore 10 heads, at the second 22, at the third 39, at the fourth 52, the best head of which was  $8\frac{3}{4}$  inches long and bore 123 grains. (Jour. Roy. Agr. Soc., Vol. XXII, p. 371, and plate.)

This was the origin of the famous "Pedigree wheat." Later, and in a similar way, he made the varieties of "Pedigree oats" and "Pedigree barley," all very prolific, and each becoming famous. He gave the name "Pedigree" to these varieties because his process was precisely analogous to that of improving live stock by breeding to points and strengthening the heredity of the good points by pedigree. Still later he gave his riper conclusions (Trans. Brit. Assoc. Adv. Sci., 1869, p. 113) drawn from his long series of experiments, in substance as follows: That every fully developed plant, whether of wheat, oats, or barley, has one ear superior in reproductive power to any of the others on the plant; that every such plant has one grain more productive than any other, and that this best grain grows on the best ear; that the superior vigor of this grain is transmissible to its progeny; that by selection this superiority is accumulated; that the improvement is at first very rapid, but that in successive years it gradually grows less; that an improved type is the result, and that by careful selection the improvement can be kept up. Another paper on his pedigree system, read before the Farmers' Club at Birmingham in 1874, giving many interesting facts, is republished in substance in the monthly reports of the United States Department of Agriculture for August and September, 1874, page 381.

The practical fact underlying this relates to selection. "Natural selection" is undoubtedly the principle by which species are preserved, whether it accounts for their origin or not, and artificial selection of seed is the only method by which any variety of grain can be improved or even maintained. Without it the variety always either runs out or changes; how rapidly this takes place depends upon various circumstances.

It is unnecessary to multiply further proofs, because all experiment points the same way, and the law is universally recognized. I have merely cited a few out of many scientific experiments. The principle is never denied; it is simply too often neglected in practice. In this connection it is well to remember that it is easier to deteriorate a crop by using bad seed, or even by simply neglecting the selection of the good, than it is to improve an already good variety; the downhill road is the easiest traveled. The selection of seed to keep up the vigor and the fruitfulness of the varieties cultivated are more

important than fertility of the soil as factors in permanent grain growing. The matter of soil exhaustion is so well known that it is the staple argument with the majority of popular writers and speakers on agriculture; but, so far as I have personally seen or have been able to learn from the observations or the experience of others, in every locality in this country where wheat growing has suddenly risen to large figures the quality and the yield have diminished more rapidly from carelessness in the selection of the seed and in the care of the crop than from mere soil exhaustion.

While there is no absolute proof that any variety of cereal has ever originated in a "sport," nevertheless the indications are that some have so originated. The new variety of Bamia cotton originated in a single plant, entirely unlike its fellows, found in a cotton field in the Nile Valley in 1873, and the variety has already nearly revolutionized cotton culture in Egypt. (McCoan, *Egypt as it Is*, p. 187, and *Kew Rept.* for 1877, p. 26, fig. 7.) Cotton is propagated from the seed as the cereals are, but the plant being a more conspicuous one, a sport would be more liable to be noticed. A single cereal plant, unlike its fellows, in a great field of grain would be gathered unnoticed unless some very unusual accident secured its preservation.

It is well known, however, that many varieties of grain have originated in some single plant differing from its fellows found growing in some exceptional place, but how that plant acquired its special characters, whether suddenly, as sports do, or not, we have no knowledge. We simply and only know that here and there some single plant has been found that represents to us a new variety ready made, and varieties have been perpetuated from such plants which have grown true to the seed and which have been valuable and enduring. The variety of oats known as "potato oats" is said to have originated in a single plant found growing in a potato patch (hence the name) in Cumberland, England, in 1778 (Allen, *New America Farm Book*, p. 163), or, as some say, in 1789 (Stephen's *Farmers' Guide*, I, 449). This variety, after nearly a hundred years' existence, is still one of the best and brings, it is said, the highest price in the English markets. Its excellence has been proved throughout Europe and entirely across the continent of America, for it is in common cultivation from Maine to Oregon and Washington.

The Clawson wheat originated in a single plant found growing by a stump in the State of New York. Darwin says that the Fenton wheat was found growing on a pile of detritus in a quarry in England. The Chidham wheat originated from an ear found growing in a hedge in the same country, and numerous other examples are recorded in the agricultural literature of this century. It is only fair to say, however, that many varieties of such origin have been rejected on trial as of no value, just as numerous varieties of seedling apples and potatoes are rejected. It is only the few that are actual improvements on what we had before. In ornamental and other garden plants the tendency to "sport" is much increased by crossing varieties, and this is probably also true of all classes of cultivated plants.

Using seed which has been grown in some other locality, or, as farmers say, "a change of seed," has been practiced by grain growers in all ages; and that this is very often attended with an increase of



crop has been proved by the experience of centuries. Sometimes this change of seed means bringing in a variety previously cultivated there by bringing it from some other place more or less distant.

To illustrate: Potatoes grow well as far south as Louisiana, the Bermudas, and other warm climates, if the seed is yearly brought from a cooler region. The same fact is true of peas, and there are large importations of seed peas from Canada to the United States every year. Most garden vegetables behave in a similar way, and on this fact the modern business of growing garden seeds is largely founded. In Connecticut, onion seed is imported from Tripoli. The first crop grown from this seed is of such excellent quality that the trouble and expense of the importation are justified; but if the cultivation is continued from seed produced by the American crop, in a few years the onions degenerate to the size of acorns. The constant sending of the seeds of squashes and other garden vines from the New England States and other places east of the Appalachians to the fertile prairie soils of the West is another familiar illustration, and similar facts have been observed all over the world. Melon seeds from Tibet are taken every year to Kashmir, and produce fine fruit weighing from 4 to 10 pounds; but vines growing from the seed of melons produced thus in Kashmir yield the next year fruit weighing but 2 or 3 pounds. Seed of the sea-island cotton have been carried to every cotton-producing country of the world, but the variety rapidly degenerates in every place yet tried distant from its original home, and if the excellency of the fiber is kept up elsewhere it is only done by the use of fresh seed.

Now, it often happens that such a variety, specially prepared for a region by a long process of adaptation, may be better suited to it than any new one, and in such cases no increase of crop follows a change of seed. For example, heavy oats taken from the cool, moist climates of Canada or northern Europe, used as seed in the northern or middle United States, usually produce at first a crop weighing more per bushel than that produced from home-grown seed. But in various places, notably so on Long Island, where special varieties have long been grown from seed carefully selected as to weight until this weight reaches that which is produced from foreign seed, no increase of weight is obtained by any change of seed. This appears to be the case in several localities reported. Another example to the point is in the local varieties of corn sometimes cultivated on farms in New England and the Middle States. Where a single variety has been cultivated for a man's lifetime in the same neighborhood, or even on the same farm each year, the seed having been carefully selected and prepared until no further improvement is reached by such selection, here it often happens that such home-bred local variety yields better than any variety introduced from without. But it also happens that, having been so long purely bred, it is of especial value in mixed planting, as already described.

## COTTON.

H. Hammond, in his report to E. W. Hilgard on the cotton production of the State of South Carolina (Tenth Census U. S., 1880, Vol. VI, p. 475), says:

In a handful of ordinary cotton seed three varieties may often be recognized, presenting well-marked differences. The largest of these is covered with a green down; another smaller and much more numerous seed is covered with a white or grayish down; the third variety is naked, smooth, and black. It may not be possible to say whether these three sorts of seeds correspond to three classes under which the numerous varieties of cotton are arranged. These are, first, the "green seed," corresponding with the *Gossypium hirsutum*, or shrub cotton, attaining a height of from 10 to 12 feet, a native of Mexico, and varying as an annual, biennial, or perennial, according to the climate in which it is grown; second, the "white seed," corresponding with the *Gossypium herbaceum*, or herbaceous cotton, an annual, attaining a height of 2 feet, native of the Coromandel coast and the Nilgherries; third, the "black seed," corresponding with *Gossypium arboreum*, or tree cotton, a native of the Indian peninsula, but attaining a height of 100 feet on the Guinea coast, and producing a silky cotton. The black seed, however, is not distinguishable from the seed of the long-staple or sea-island cotton.

## HISTORY OF THE LONG-STAPLE COTTON.

It would be a matter of much interest to determine the origin and history of the varieties of cotton now in cultivation. The difficulties of doing this are much increased by the very wide geographical range occupied by the plant. The earliest explorers, Columbus, Magellan, Drake, Captain Cook, and others, seem to have found it almost everywhere in the broad belt extending from the equator to 30° south and to 40° and 45° north latitude, where it now grows. Although it is not found among those oldest of vestments, the wrappings of Egyptian mummies, its use was known to man in Europe, Asia, Africa, America, and the outlying islands of the sea in the remote past, far beyond the historic age. Its very name itself bears evidence to this, occurring, as it does, in many and in the most ancient languages.

Nevertheless nothing can show more clearly the importance of tracing and understanding the history of plants under cultivation than the variation and improvements in black seed cotton since its introduction on the Carolina coast. It is known that the first bale of long-staple cotton, exported from America in 1788, was grown on St. Simons Island, Georgia, by a Mr. Bissell, from seed that came from either the Bahamas or the Barbadoes Islands.<sup>a</sup> Singularly enough, the authorities leave this matter in doubt, the Hon. William Elliott saying it came from Anguilla, one of the Bahamas,<sup>a</sup> and Signor Filippo Partatori (Florence, 1866), saying it came from Cat Island, one of the Barbadoes.<sup>a</sup> But as Anguilla is one of the Barbadoes<sup>a</sup> and Cat Island one of the Bahamas<sup>a</sup> it would seem difficult to decide to which group of islands we are indebted for these seed. However, as Mr. Thomas Spalding, of Sapelo Island, says, in a letter to Governor

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<sup>a</sup> *Sic.*



Seabrook, in 1844, that three parcels of long-stapled cotton seed were, to his knowledge, brought in 1785–86 from the Bahamas to a gentleman in Georgia, it would seem certain that the seed reached our coast from those islands. There it was known as *Gossypium barbadense*, as coming from the Barbadoes. In the Barbadoes it was called Persian cotton, the seed having been brought from that country. In this manner its descent from the *G. arboreum* of India is traced.

Be this as it may, Mrs. Kinsey Burden, Burden Island, Colleton County, S. C., obtained some of these seeds from Georgia and planted them. This crop failed to mature, and the first successful crop of long-staple cotton grown in South Carolina was planted in 1790 by William Elliott, on the northwest corner of Hilton Head, on the exact spot where Jean Ribault landed the first colonists and erected a column of stone, claiming the territory for France a century before the English settled on the coast. Mr. Elliott's crop sold for 10½d. per pound. Other planters made use of this seed, but it was not until Kinsey Burden, sr., of Colleton County, began his selections of seed, about the year 1805, that attention was strongly called to the long staple. Mr. Burden sold his crop of that year for 25 cents per pound more than did any of his neighbors. He continued to make selections of seed and to improve his staple, and in 1825 he sold a crop of 60 bales at \$1.16 per pound. The year subsequent his crop sold for \$1.25, and in 1828 he sold 2 bales of extra fine cotton at \$2 per pound, a price not often exceeded since. The legislature was on the point of offering Mr. Burden \$200,000 for his method of improving the staple of cotton, and Mr. William Seabrook, of Edisto, was prepared to pay him \$50,000 for his secret, when it was discovered that the fine cotton was due wholly to improvements made in the seed by careful and skillful selection. Since then the greatest care has been bestowed upon the selection of the seed, and to such perfection was the staple brought by this means that the crops of some planters were sold not by sample, but by the brand on the bale, as are the finest wines.

During the war of 1861–1865, the cultivation of the finest varieties being abandoned on the islands, the seed removed to the interior greatly deteriorated in quality. So scarce, on this account, was good seed directly after the war that J. T. Dill, a cotton merchant in Charleston, at one time had, in an ordinary letter envelope, the seed from which are derived all the better qualities of long staple now cultivated. Nor have the improvements made by careful selection of the seed ceased in later years. The staple has kept fully up to the best grades of former days, and the proportion of lint to seed cotton has been increased. Formerly 1 pound of lint cotton from 5 pounds of seed cotton of the fine varieties was considered satisfactory. Thanks to the efforts of Mr. E. M. Clark, a cotton has been recently found which yields 1 pound of lint to 3½ of seed cotton, preserving at the same time the length, strength, and evenness of fiber characteristic of the best varieties.

#### BEANS.

The history of the derivation of the bean (*Vicia sativa*, *Vicia faba*, and *Ervum lens*) is given by A. de Candolle (see Agr. Sci., Vol. I, p. 58), who shows that its cultivation began in Persia, and that the common white bean, which has been cultivated since prehistoric times

in Europe, has some similarity to a bean cultivated in India since the earliest times. The characteristic peculiarities of the cultivated bean and its uncultivated relatives have probably existed for at least five or six thousand years, and the original stock from which the cultivated bean was derived has long since become extinct.

#### PEPPER.

The derivation and varieties of peppers from all parts of the world (genus *Capsicum*) are described by E. L. Sturtevant (Agr. Sci., Vol. II, p. 1). The general effect of climate is to diminish the size of the fruit when the seeds are planted in higher latitudes—that is to say, with a diminution of temperature. Similarly, the effect of cold nights is to check the growth, diminish the size, and promote early ripening.

#### KENTUCKY BLUE GRASS.

The germination of Kentucky blue-grass seed (*Poa pratensis*), as also that of red top and timothy, has been studied by Thomas F. Hunt at the agricultural experiment station, Champaign, Ill. Although the object of the experiment was primarily to determine the relative vitality or honesty of the seeds and samples from different sources, yet the results have some bearing upon the question as to the best temperature for germination and the possibility of acclimatization. Kentucky blue grass, raised in Kentucky, when sown in the Geneva sprouting apparatus, would not germinate in thirteen weeks at temperatures from 70° to 80° F., whereas 80 per cent of meadow fescue and 95 per cent of mammoth red clover sprouted during the first week in June, 1888. Again, in 1889 a specimen of blue grass from the same locality would not sprout in sixty days at an average temperature of 67° F., whereas during the first eight days 98 per cent of both timothy and red clover and 85 per cent of meadow fescue sprouted. Again, a sample from another dealer in Kentucky, tested for thirty days under similar conditions as the last, gave one sprout to a hundred seeds. Another sample was sent from Chicago to Manitoba and thence to Champaign for testing. Out of 500 seeds not one sprouted, but in the best of subsequent samples 7 per cent sprouted.

Finally, samples were obtained from 19 different sources, mostly in Kentucky, and were all tested uniformly in the Geneva apparatus at Champaign, Ill., from July 23 to August 31, 1889. The range of temperature in the apparatus was from 63.5° to 73.5° F. Out of all

the samples the maximum and the minimum percentages of sprouting were as shown in the following table:

Variety.	Maximum.	Minimum.	Average of 19.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Kentucky blue grass.....	7	0	2
Red top .....	68	4	25
Timothy .....	96	42	76

These are not likely to be abnormal percentages, since, according to Professor Hunt's calculation, with an ordinary seeding of 30 pounds to the acre, if only 2 per cent germinates there would be 40 plants to the square foot. But the question may still remain as to whether the soil or the temperature were unfavorable or whether the seed of the Kentucky blue grass was in some abnormal condition. (Agr. Sci., Vol. IV, p. 4.)

## Chapter XII.<sup>a</sup>

### RELATIONS OF SPECIAL CROPS TO SPECIAL FEATURES OF CLIMATE AND OTHER INFLUENCES.

The preceding chapter on phenology has given several illustrations of the influence of the date of planting upon the dates of the resulting phases and on the amounts of the harvest for special plants. The experiments at experiment stations now about to be quoted were undertaken with a view to the further direct elucidation of this relation. From such experiments we obtain definite data by which to decide as to the best date for planting and the probable resulting crop both in normal and abnormal seasons. We see to what extent the seed and plant have acquired habits suitable to the prevailing climate, and furthermore, what climatic influences the plants were not able to withstand when the seeds were planted too early or too late. It is, of course, of prime importance in each case to know where the seeds were grown or to what climate they were acclimatized before being planted at the experiment station.

By measuring the weight and nutritious value of a sample of a crop at various stages of development we are able to form tables showing the relation of the mature ultimate harvest to the immature plant, and this relation is found to be sufficiently constant to justify one in predicting the harvest per acre from its condition on any given day several months before harvesting. Examples of this process have already been given and others now follow.

#### BEETS AND POTATOES.

##### DATE OF PLANTING.

Briem finds the crops of beets and potatoes that have become acclimatized in Austria-Hungary vary with date of planting, as given in the table following.

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<sup>a</sup> A chapter on "Forests and climate," which was originally intended to precede this chapter, is omitted.

Date of sowing.	From sowing to harvest. <sup>a</sup>				Average weight of one tuber.	
	Number of days.	Sums of mean daily temperatures.	Number of days when rain fell.	Total rain-fall.	Beet.	Potato.
		° C.		mm.	Grams.	Grams.
March 1 .....	284	8,271	108	519	208	198
March 16 .....	219	8,209	108	506	231	222
April 1 .....	203	8,151	102	496	207	272
April 16 .....	188	8,080	94	453	304	257
May 1 .....	173	8,881	87	417	306	302
May 16 .....	158	2,726	80	373	206	228
June 1 .....	142	2,469	68	294	211	217
June 16 .....	127	2,197	55	169	82	173
July 1 .....	112	1,890	48	154	75	158
July 16 .....	97	1,627	37	122	52	86
August 1 .....	81	1,381	31	99	14	47
August 16 .....	66	1,026	35	76	18	22

<sup>a</sup> Harvest October 20.

SUGAR BEETS.

Durin has shown that the sugar beet loses the sugar in the root by its consumption in forming stalks and leaves as well as seeds. The roots die when all the sugar is used up, from which I infer that the best time for gathering the beets must be at that period of ripeness in which the formation of leaves ceases, and possibly this formation of leaf and loss of sugar can be checked artificially by cutting the young leaves. (Agr. Sci., Vol. IV, p. 326.)

GRASSES.

The changes in the chemical composition of grass and in the nutritious quality of the dried hay have been determined by E. F. Ladd (Agr. Sci., Vol. I, p. 221) by experiments on timothy (*Phleum pratense*), who concludes as follows:

- (1) The amount of water in timothy diminishes rapidly.
- (2) There was a large increase in crude fiber in late-cut timothy over that cut at the period of full bloom.
- (3) As the grass approached maturity there was a considerable diminution in the percentage of sugar and an increase of the starch.
- (4) After the period of full bloom the proportion of albuminoids to the other organic constituents diminished.

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(8) Finally, from a chemical point of view, it seems preferable to cut timothy for feeding at the period of full bloom, rather than after the seeds have formed. (Agr. Sci., Vol. I, p. 223.)

The effect of climate on the yield and chemical composition of

grasses, especially the pasture grass, has been studied at the Pennsylvania State College Agricultural Experiment Station, by G. L. Holter (Agr. Sci., Vol. III, p. 285), in connection with studies on the yield per acre. Samples of grass were cut every few days during the season (of 1887), but the comparisons with rainfall and temperature showed no definite relation, except, perhaps, that the percentage of ash increased as the temperature diminished. The following table gives the figures showing the average rainfall and temperature from the middle of one period to the middle of the next, and for the average of seven plats of ground:

Period.	Rain-fall.	Tem-perature.	Yield per acre, in pounds.		Period.	Rain-fall.	Tem-perature.	Yield per acre, in pounds.	
			Fresh grass.	Dry hay.				Fresh grass.	Dry hay.
	<i>Inches.</i>	<i>° F.</i>				<i>Inches.</i>	<i>° F.</i>		
May 5-22 .....			1,300	389	Aug. 29-Sept. 5 ..	0.88	66.5	147	38
May 25-June 4 ..	2.62	61.0	525	130	Sept. 10-14 .....	1.56	60.2	216	52
June 6-12 .....	0.52	62.2	325	91	Sept. 18-21 .....	1.50	60.4	202	53
June 13-22 .....	0.23	70.0	140	41	Sept. 22-29 .....	0.41	60.2	84	24
June 25-July 2 ..	1.75	75.3	229	65	Sept. 29-Oct. 2 ..	0.39	55.9	85	21
July 3-11 .....	0.51	67.2	171	50	Oct. 15-17 .....	0.85	45.2	32	11
July 13-20 .....	1.74	67.9	247	67	Oct. 17-22 .....	1.42	46.1	43	16
July 21-29 .....	0.72	69.2	170	45	Oct. 30-Nov. 5 ..	1.37	45.6	9	3
July 30-Aug. 7 ..	0.25	75.2	101	34	Total .....			4,277	1,145
Aug. 8-20 .....	1.48	72.6	105	23					
Aug. 22-28 .....	3.24	68.6	145	43					

If we assume that the whole season extended from May 10 to September 29, we may compute the average daily growth, which will be found to be very large at first, but rather uniform from June 13 to September 16, after which it steadily diminishes. The irregularities in the growth from one week to the next have no simple connection with rainfall or temperature, but there is no evidence to show that other climatic elements, such as sunshine and evaporation, would not have thrown some light upon the subject.

Mr. Holter has also experimented on the yield per acre of pasture grass, as measured week by week during the growing season of 1888 and 1889 at the Pennsylvania State College Agricultural Experiment Station. (See Agr. Sci., Vol. V, p. 52.) The plat experimented upon represents an average of the uplands of the Allegheny Mountains. The weather of the season was most favorable for the growth of grass, having a heavy, evenly distributed rainfall. The following table shows the dates of cutting and the average daily growth between these dates, expressed in pounds of dried grass per acre. It will be seen that there was a rapid increase in growth up to May 21, after which there was a steady decline. The daily average for the whole season of one hundred and seventy-eight days

is 32.13 pounds of fresh matter and 9.06 of dry matter. Evidently a pasture that is fairly well stocked with cattle in May and June will be overstocked in August and September.

Date of cutting.	Weight of dry matter.	Date of cutting.	Weight of dry matter.	Date of cutting.	Weight of dry matter.
	<i>Pounds.</i>		<i>Pounds.</i>		<i>Pounds.</i>
April 20 .....	0.00	June 17 .....	13.26	August 9 .....	8.58
May 1 .....	4.86	June 22 .....	13.04	August 16 .....	7.96
May 9 .....	8.69	June 28 .....	9.78	August 23 .....	8.48
May 15 .....	15.98	July 5 .....	13.41	August 29 .....	5.78
May 21 .....	20.01	July 11 .....	8.77	September 9 .....	4.66
May 24 .....	15.29	July 17 .....	9.74	September 23 .....	5.35
May 29 .....	12.48	July 23 .....	11.46	October 4 .....	4.32
June 5 .....	12.81	July 29 .....	9.79	October 15 .....	1.78
June 11 .....	13.49	August 3 .....	13.91		

CEREALS.

C. Richardson (Agr. Sci. Vol. I, p. 125) states that the quality of the grain produced in any locality is dependent principally on three conditions—the climate, the soil, and the cultivation. Wheat is most susceptible to its environments; thus the Atlantic slope produces a wheat grain of medium size and with less than the average amount of nitrogenous constituents. In this part of the country latitude exerts a minor influence.

In the Central States—Tennessee, Kentucky, Arkansas—the grain is larger and contains more nitrogen.

In the Northwest a grain is harvested smaller than anywhere and richer in nitrogen.

In Colorado, where irrigation is practiced, a large grain is grown which is rich in nitrogen.

On the northwest Pacific slope the grain is large, very starchy, and with less nitrogen than anywhere else.

The above conditions, as at present existing, are probably in a state of transition.

The following table shows the difference in the composition of the crops of standard varieties of wheat in Minnesota and Dakota:

Crop.	Albumi- noids.	Crop.	Albumi- noids.
	<i>Per cent.</i>		<i>Per cent.</i>
1882 .....	13.21	1884 .....	14.28
1883 .....	15.14	1885 .....	15.99



The following table shows the differences for the varieties raised in the respective States:

	Weight of 100 kernels.	Albumi- noids.		Weight of 100 kernels.	Albumi- noids.
	<i>Grams.</i>	<i>Per cent.</i>		<i>Grams.</i>	<i>Per cent.</i>
All North America.....	3.644	12.15	Ohio.....	3.476	12.83
Atlantic slope.....	3.489	11.85	Tennessee.....	3.150	12.50
Central States.....	3.684	12.66	Kentucky.....	3.454	13.15
Northwest.....	3.205	14.07	Virginia.....	3.433	12.10
North Pacific.....	4.091	9.73	Georgia.....	3.579	11.78
Canada.....	3.325	10.87	Alabama.....	3.424	11.29
Michigan.....	3.969	11.67			

The effect of climate and soil on wheat is strikingly shown in that a soft plump yellow wheat from Oregon and a small hard red variety from Minnesota, when used as seed in Colorado, in three years' time had lost nearly all their differences, so as to look more like Colorado grain than like their own originals.<sup>a</sup>

A study of 38 varieties grown during seven years on one farm in Colorado shows a progressive change, as in the following table:

Year.	Weight of 100 grains.	Albumi- noids.	Weight per bushel.	Year.	Weight of 100 grains.	Albumi- noids.	Weight per bushel.
	<i>Grams.</i>	<i>Per cent.</i>	<i>Pounds.</i>		<i>Grams.</i>	<i>Per cent.</i>	<i>Pounds.</i>
1881.....	4.865	13.40	.....	1884.....	4.222	12.53	65.2
1882.....	4.283	13.04	.....	1885.....	3.810	11.84	62.2
1883.....	3.941	11.74	.....				

These determinations show plainly that the soil and other conditions in 1885 would not produce as good a crop from introduced seed as in 1881, and that the drop in character of the crops as a whole is due as much or more to soil than to season. The seven varieties grown for several years in Colorado which showed no signs of deterioration are on this account worth considering, since they are perhaps the varieties to select for the locality, because they may be more suited to the conditions there existing than any others. Attention is called to the fact that deterioration in quality, as evidenced by diminution of albuminoids, is shown by the loss of weight per bushel. In the present case a drop of 1.2 per cent in albuminoids was accompanied by a loss in weight of 3 pounds per bushel. No other cereal seems to be influenced by its environment in the same way as wheat. Oats are more changed, by climate and soil, in the outward physical appearance and properties of the grain; barley is modified in its

<sup>a</sup> There is nothing to show how much this may have been due to spread of pollen from one field to the other.—C. A.

chemical composition; maize is modified as to its size; rye varies very little with change of conditions, except as to the effect upon the straw; but, as we have seen, wheat changes both its external appearance and its chemical constituents.

With regard to maize, the high ripening temperature of the Southern States appears to diminish the size of the kernel and prevent a large formation of starch. But the variations in size peculiar to the varieties are much smaller than variations that are due to the climate and soil, thus Dent varieties of corn from Tennessee and Indiana have been found weighing, respectively, 64.1 and 13.9 grams per 100 kernels, or a ratio of 5 to 1 in the weights of the kernels. Hence a comparison of the yield per acre by the weights of the crops would differ very much from a comparison by volumes in bushels. The percentage of albuminoids varies very much less in the large and small kernels of maize.

As to oats, the climatic surroundings cause a very large variation in their physical appearance. The extreme weights per bushel are 48.8 and 24.7 pounds; the extreme ratios in the weight of the kernel, with reference to the weight of the kernel plus the hull, are 79 and 55 per cent. The average composition all over the country as to the percentage of albuminoids is between 12 and 10 per cent, except in a few extreme cases of 9 and 19 per cents, which are as liable to occur in one locality as in another.

Barley is not as variable in composition and appearance as wheat and oats; the extreme weights per bushel are 60.2 and 50.4 pounds, and the extreme weights of 100 kernels are 4.900 and 2.630 grams; the extreme percentages of albuminoids are 14.88 and 8.75. For malting purposes the large quantity of albuminoid is not desirable, while starch is desirable.

#### **WHEAT—GENERAL RELATIONS TO CLIMATE AND SOIL.**

In his tenth census report Professor Brewer says:

While the cultivation of wheat in a commercial sense is determined by a complicated set of conditions, in an agricultural sense the matter is very much simpler. The yield and quality of the crop practically depends upon but five conditions—the climate, the soil, the variety cultivated, the method of cultivation, and the liability to destruction by insects. Even under poor cultivation and exemption from insect depredations, if the other three conditions are favorable good crops of wheat of good quality may be very often grown, and in a good climate and with a good variety of wheat an excellent quality may be grown even where the soil is comparatively poor. The yield may be small, but the grain itself will be good.

As regards soils, we may say in a general way that light clays and heavy loams are the best for wheat. On the one hand, very heavy

clays often produce good crops, both as to yield and as to quality, and on the other hand the lighter soils may yield a good quality. It is simply smaller in quantity. The best crops, however, come from moderately stiff soils, but any fertile soil will produce good wheat if all the other conditions are favorable.

Geologically considered, the most of the wheat grown in the United States is over the region of drift, but much of the wheat soil has been so modified by other geological influences that the geological factor is not an important one, the essential character which gives it its value being as largely physical as chemical. Good wheat lands agree in this, that they are sufficiently rolling for natural drainage; are at the same time level enough to admit of the use of field machinery, and are easily tilled, admitting the use of light field implements in their tillage and thus allowing of a very large production of grain in proportion to the amount of human labor employed. The facility of putting in the crop and harvesting it is really the controlling condition in many localities, so much so that the very important wheat regions, where some of the most speculative farming of the United States is practiced, are in regions where the climatic conditions are such that the average yield one year with another may be as low as 10 bushels per acre. In such cases this low average is usually due to climatic reasons rather than to a lack of fertility in the soil, and in favorable years the yield may be very much larger. The ease of cultivation, the facilities for gathering the crop, and its good qualities in favorable years incite to the hope that all years will be favorable, and in good years the profits are large. In color, in the amount of clay contained, in physical and in chemical characters, there is much difference in the different soils of the country. Some contain much vegetable matter, others but little. We may say that the soils of all the more important wheat regions (so far as we have chemical analyses) are rich in lime, as well as in those other elements of fertility, such as potash and phosphoric acid, which are necessary for a good crop and a good quality of grain.

For commercial as well as for agricultural success climate is an all-controlling condition. Wheat is normally a winter annual. For a good crop the seed must germinate and the young plant grow during the cool and moist part of the year, which season determines the ultimate density of growth on the ground and, consequently, mostly determines the yield. Wheat ripens in the warmer and drier parts of the year, which season more largely determines the quality, plumpness, and color of the grain. In climates with winters so cold that all vegetable growth is suspended we have two distinct classes of varieties, known, respectively, as spring and winter wheats. Throughout all the Northern States, from ocean to ocean, and to some extent in those Southern States which lie east of the Great Plains, these two classes of varieties are very distinct as regards their cultivation and to some extent also as regards their characters. In California and in similar climates, as in Egypt, this distinction does not exist in respect to their cultivation, although the varieties partake more of the character of winter wheats than of spring, both in their mode of growth and in the character of the flour made from them.

But in all climates and whatever variety may be grown, the crop must be sown and have its early growth in a cool part of the year.

Wheat branches only at the ground, and produces no more heads than stalks. It only sends out these branches early in its growth or during cool weather and when the growth is comparatively slow. The branching of wheat (called "tillering" in the Old World, and "stocking," "stooling," and "tillering" in different sections of this) must take place before the plant attains any considerable height or it does not occur at all. Hence, in climates like those of the Northern and Eastern States this takes place mostly in the spring, and a cool, prolonged, and rather wet spring is therefore best for the ultimate yield of the crop; the grain then stands heavier on the ground. On the contrary, a warm, rather dry, rapidly growing, and early spring in those parts of the country diminishes the yield of wheat, because of this habit of growth; there are then fewer stalks, and the heads are fewer. Consequently, when from the nature of the season or the general climate of the region there is an undue tendency for the wheat to shoot up without sufficient branching it is common to check the growth by pasturing off the grain in the early spring, as is a common practice in many of the Southern States.

In a country of cold winters, for good crops it is better that the ground be continuously covered with snow. Bare ground, freezing and thawing, now exposed to cold and dry winds and now to warm sunshine, is exceedingly destructive to wheat. It "winter-kills" in two ways—what may be frozen to death by cold, dry winds, or, as is more often the case, particularly on soils rich in vegetable matter, it "heaves out," and by the alternate freezing and thawing of the surface soil the roots are lifted out of the soil and the young plant perishes. The means of guarding against this or of lessening the danger will be spoken of later.

After the wheat comes in head more sun is needed and less rain. Too much rain, particularly if accompanied with heat, induces rust, mildew, and other diseases, and, on the other hand, too dry winds shrink the grain.

The ideal climate for wheat is one with a long and rather wet winter, with little or no frost, prolonged into a cool and rather wet spring, which gradually fades into a warmer summer, the weather growing gradually drier as it grows warmer, with only comparatively light rains after the blossoming of the crop, just enough to bring the grain to maturity, with abundant sunshine and rather dry air toward the harvest, but without dry and scorching winds until the grain is fully ripe, and then hot, dry, rainless weather until the harvest is gathered. This ideal is nearer realized in the better years in California than in any part of the United States, and it is there in such years that we find the greatest yields known to the country.

The quality of the grain is largely determined by the climate, a hot, dry, and sunny harvest time being best for wheat of the first grade. The berry is then brighter, and millers say the quality is better if the climate has been hot and dry before the harvest. The wheat of sunny climates—those of California, Egypt, northern Africa, and similar countries—has always ranked high for quality, and the statement is often made that the wheat of such climates is also richer in gluten—that is, makes stronger flour—than the wheat of cooler climates. Of this latter assertion I find no proof from the modern and fuller chemical analyses. The chemical composition depends

more upon the variety cultivated than upon either soil or climate. The spring wheat of Dakota and Minnesota produces as strong flour as does grain from a sunnier climate. It is true that certain varieties of very hard wheats only grow in hot, dry climates. Such is said to be the case with the best macaroni wheats. It is claimed that the macaroni wheats of California are equal to the best of northern Africa or of southern Europe and that the macaroni made from it in San Francisco is equal to the best Italian. But while, as a whole, the quantity of gluten and the strength of the flour is determined more by the variety of wheat than by the climate or the soil, yet both of the latter have their influence on chemical composition. Although direct chemical evidence is lacking, derived from a large number of chemical analyses from samples chosen with this special object in view, it is claimed that abundance of phosphates in the soil increases the quantity of gluten in the crop. The millers of western New York say that the flour has grown stronger with the increase in the use of superphosphates in growing wheat in that region, and that the same has often been stated as a fact in English experience.

The particularly bright character of American grain, however, depends upon the climate rather than upon the soil. The sunny climate of the whole United States south and west of New England is favorable for this, and from the time of the first settlement of the colonies the bright color of American grain, as compared with that of northern Europe, particularly that of Great Britain, has been remarked.

The table of distribution according to annual temperature (Tenth Census, Cereals, Table XIX, p. 14) shows that the greatest production is where the mean annual temperature is between  $50^{\circ}$  and  $55^{\circ}$ , 173,895,149 bushels, or 37.8 per cent, being grown in this belt, and 136,401,822, or 29.7 per cent, where the mean annual temperature is between  $45^{\circ}$  and  $50^{\circ}$ . Adding these two, we see that 310,296,971 bushels, or 67.5 per cent, is grown where the mean annual temperature is between  $45^{\circ}$  and  $55^{\circ}$ . Considered in respect to the midsummer or July temperature (Table XX, p. 14), which has much to do with the ripening of the grain, our figures are of less interest in this crop, because over considerable regions of the country the crop is already ripe before July begins, notably in California; but we find that 223,852,371 bushels, or 48.7 per cent, grows where the mean temperature of July is between  $70^{\circ}$  and  $75^{\circ}$ , and 178,530,037 bushels, or 38.9 per cent, where the midsummer temperature is between  $75^{\circ}$  and  $80^{\circ}$ , or an aggregate of 87.6 per cent where the July temperature is between  $70^{\circ}$  and  $80^{\circ}$  and 97.3 per cent where it is between  $65^{\circ}$  and  $85^{\circ}$ . While the ideal climate for wheat is one of mild winters, and some of the most noted wheat regions of the world are where snow and frozen ground are unknown or very rare (as in Egypt, India, and California), nevertheless most of the wheat of the world grows in regions of cold winters.

The table of distribution according to mean winter temperature (Tenth Census, Cereals, Table XXI, p. 15) shows that in this country 46.6 per cent grows where the mean January temperature is between  $20^{\circ}$  and  $30^{\circ}$ , 68.9 per cent where it is below  $30^{\circ}$ , and it is safe to say that 70 per cent of the wheat crop of the country is grown where the



average January temperature is below the freezing point. This same condition marks most of the great wheat regions of the world.

The wheat countries (which are also the countries of oats, barley, and rye) are where the summer season only is the growing season, and the comforts of winter must be provided for by forethought and labor; and hence they are also the countries of labor, industry, and enterprise, and where the highest civilization has been developed, the result being correlated to these climatic conditions.

The table of distribution according to rainfall (Table XXII, p. 16) shows that 132,152,234 bushels, or 28.8 per cent of the crop, grows with an annual rainfall of between 40 and 45 inches, 62.7 per cent where it is between 35 and 50 inches, and 92.4 per cent where the annual rainfall is above 25 inches, although some important wheat regions, notably those of California, are where the mean annual rainfall is less than 25 inches. We have an explanation of this in the seasons at which the rain falls. The table of distribution according to the rainfall of the growing season (Table XXIII, p. 16) shows that 220,656,637 bushels, or 48 per cent of the crop, grows where from 20 to 25 inches of rain falls during this season, and 366,381,658 bushels, or 79.7 per cent, where the rainfall during the growing season is from 15 to 25 inches, 6.4 per cent where it is below 15 inches, and only 1 per cent where it is less than 10 inches—a fact of much significance for great tracts of our country.

#### **CULTIVATION OF CEREALS—EXPERIMENTS AT BROOKINGS, S. DAK.**

##### **WHEAT.**

The first annual report of this station, for the year ending June 30, 1888, gives following table of results of experiments on different varieties of wheat, at Brookings, S. Dak. (lat. 44.3° N.; long. 98.5° W.), in April and May, 1887, on plats of ground that had already borne one crop of wheat or flax or oats. Some were sown broadcast and had no subsequent cultivation; others were “drilled by hand” and subsequently hoed twice or thrice.

The columns giving the calculated sums of degrees of temperature are based upon observations at the Signal Service station at Huron, some distance to the westward, because the special station at Brookings was not then established. The meteorological table for Huron follows the agricultural tables, so that the student may make such further studies as he desires. A fragment of the meteorological record at Brookings for 1888 is given in the station Bulletin No. 5, which I have compared with the record for Huron and find that no important error will result from using the Huron records.

Variety.	Date of sowing.	Date of harvesting.	Sums of positive temperatures (T - 43° F.).
<b>Sown broadcast:</b>	1887.	1887.	° F.
Saskatchewan Fife .....	Apr. 25	Aug. 1	2,367
French Imperial .....	do	July 29	2,279
<b>Hand drilled:</b>			
Blount, Colorado .....	Apr. 30	Aug. 10	2,518
Wellman's Saskatchewan .....	do	Aug. 9	2,484
Pure Scotch Fife .....	do	Aug. 6	2,397
Russian Fife .....	May 3	Aug. 11	2,514
China Tea .....	do	do	2,514
Velvet Chaff or Blue Stem .....	do	July 29	2,168
Blount's Hybrid, No. 15 .....	Apr. 30	Aug. 9	2,484
Blount's Hybrid, No. 17 .....	May 3	Aug. 6	2,373
Champlain .....	May 8	Aug. 8	2,311
Golden Drop .....	May 3	Aug. 4	2,326
Blount's Rust Proof .....	do	Aug. 8	2,437
Peerless or Black Bearded .....	do	Aug. 20	2,728
Pringle's Grandee .....	do	Aug. 12	2,584

#### BARLEY.

The following table gives the results of experiments on different varieties of barley at Brookings, S. Dak., as given in the first annual report of that station. For further details see the preceding section on wheat experiments.

Variety.	Date of sowing.	Date of harvesting.	Sums of positive temperatures (T - 43° F.).
<b>Sown broadcast:</b>	1887.	1887.	° F.
Scotch .....	Apr. 25	July 18	1,977
Chevalier .....	do	July 23	2,005
Wisconsin Manshury .....	do	July 18	1,977
Imperial Hybrid .....	do	do	1,977
<b>Hand drilled:</b>			
Manshury .....	May 5	July 23	1,946
Two-Rowed .....	do	July 22	1,922
Melow .....	do	July 20	1,880
Imperial .....	do	July 25	2,010
Four-Rowed .....	do	do	2,010
Barley No. 8 .....	do	July 20	1,880
Black Hulless .....	do	July 28	2,009



## OATS.

The following table gives the results of experiments on different varieties of oats at Brookings, S. Dak., as given in the first annual report of that station. For further details see the preceding section on wheat experiments.

Variety.	Date of sowing.	Date of harvesting.	Sums of positive temperatures (T-43° F.).
<b>Sown broadcast:</b>	1887.	1887.	°F.
Probstler .....	Apr. 23	July 29	2,279
Welcome .....	Apr. 25	do	2,279
White Belgium .....	do	Aug. 1	2,367
Wide Awake .....	do	Aug. 8	2,319
White Bonanza .....	Apr. 26	Aug. 1	2,365
Hargett's White Seizure .....	do	July 22	2,069
<b>Hand drilled:</b>			
White Victoria .....	May 5	Aug. 3	2,270
Black Norway .....	do	Aug. 8	2,399
Black Tartarian .....	do	do	2,399
Dakota Chieftain .....	do	Aug. 1	2,218
No Name .....	do	do	2,218
Golden Russian .....	do	July 28	2,099
White Surprise .....	do	Aug. 1	2,218
Holstein .....	do	do	2,218

The meteorological record for the "growing season" of 1887 at Huron is now given for detailed comparisons. The last three columns give the temperatures computed by the two methods of Boussingault and Angot, respectively.

*Meteorological data for Huron, Dak., in 1887.*

Date.	Mean daily temperature.	Dew point.	Relative humidity.	Wind.	Clouds.	Rain.	Frosts.	Positive temperature (T-43° F.).	Sum of daily temperature.		
									All.	All above 43° F.	All positive (temperature above 43° F.).
1887.	°F.	°F.	Per ct.	Miles.	Per ct.	In.	Date.	°F.	°F.	°F.	°F.
Apr. 1	47	28	55	127	67	.....	1	4	47	47	4
2	48	33	60	151	83	0.03	.....	5	95	95	9
3	26	15	64	437	100	.02	.....	.....	121	95	9
4	28	17	64	250	20	.....	.....	.....	149	95	9
5	40	22	52	222	50	.....	.....	.....	189	95	9
6	47	29	54	137	13	.....	6	4	236	142	13
7	53	33	53	354	7	.....	7	10	239	195	23
8	73	33	32	514	53	.04	.....	30	362	268	53
9	64	47	57	476	70	.20	.....	21	426	332	74
10	39	30	72	365	93	.21	.....	.....	465	332	74
11	52	44	76	323	67	.61	.....	9	517	384	83

Meteorological data for Huron, Dak., in 1887—Continued.

Date.	Mean daily temperature.	Dew point.	Relative humidity.	Wind.	Clouds.	Rain.	Frosts.	Positive temperature (T—43° F.).	Sum of daily temperature.		
									All.	All above 43° F.	All positive (temperature above 43° F.).
1887.	°F.	°F.	Per ct.	Miles.	Per ct.	In.	Date.	°F.	°F.	°F.	°F.
Apr. 12	54	43	72	60	67	-----	-----	11	571	438	94
13	49	47	93	300	100	1.77	-----	6	620	487	100
14	41	37	89	265	67	.10	-----	-----	661	487	100
15	38	30	75	369	100	.12	-----	-----	669	487	100
16	43	35	75	58	100	-----	-----	0	742	487	100
17	43	28	59	52	70	-----	-----	0	785	487	100
18	44	25	50	85	0	-----	18	1	829	531	101
19	45	26	53	109	33	-----	19	2	874	576	103
20	47	27	54	158	10	-----	-----	4	921	623	107
21	46	40	81	413	70	.56	-----	3	967	669	110
22	35	23	62	676	50	.10	-----	-----	1,002	669	110
23	32	23	69	278	67	.03	23	-----	1,034	669	110
24	34	25	68	222	80	.06	-----	-----	1,068	669	110
25	41	23	51	147	0	-----	25	-----	1,109	669	110
26	45	33	64	144	17	.05	-----	2	1,154	714	112
27	56	38	55	329	93	.02	-----	13	1,210	770	125
28	58	33	44	306	33	-----	-----	15	1,268	828	140
29	70	39	36	473	47	-----	-----	27	1,338	898	167
30	73	46	41	358	20	-----	-----	30	1,411	971	197
May 1	57	45	64	301	27	-----	-----	14	1,468	1,028	211
2	39	31	73	634	80	.08	-----	-----	1,507	1,028	211
3	53	26	42	235	3	Tr.	3	10	1,560	1,081	221
4	61	35	47	334	0	-----	-----	18	1,621	1,142	239
5	63	34	43	254	17	-----	-----	20	1,684	1,205	259
6	72	43	39	434	33	-----	-----	29	1,756	1,277	288
7	75	49	44	657	33	-----	-----	32	1,831	1,352	320
8	70	40	41	287	0	-----	-----	27	1,901	1,422	347
9	72	44	43	214	0	-----	-----	29	1,973	1,494	376
10	74	48	43	365	13	-----	-----	31	2,047	1,568	407
11	71	51	52	351	23	-----	-----	28	2,118	1,639	435
12	68	57	67	384	77	-----	-----	25	2,186	1,707	460
13	65	55	76	359	93	.69	-----	22	2,251	1,772	482
14	57	39	56	314	27	-----	-----	14	2,308	1,829	496
15	62	44	58	207	60	.01	-----	19	2,370	1,891	515
16	44	36	74	377	93	.04	-----	1	2,414	1,965	516
17	51	37	62	116	3	-----	-----	8	2,465	1,986	524
18	63	45	56	367	0	-----	-----	20	2,528	2,049	544
19	73	52	50	559	0	-----	-----	30	2,601	2,122	574
20	75	57	55	470	37	-----	-----	32	2,676	2,197	606
21	59	54	83	302	87	.48	-----	16	2,735	2,256	622
22	57	47	70	211	57	.03	-----	14	2,792	2,313	636
23	60	46	63	324	17	.02	-----	17	2,852	2,373	653
24	56	38	55	221	0	-----	-----	13	2,908	2,429	668
25	62	40	52	79	3	-----	-----	19	2,970	2,491	685
26	66	43	50	331	0	-----	-----	23	3,036	2,557	708
27	66	45	52	136	17	-----	-----	23	3,102	2,623	731
28	61	53	76	208	33	.04	-----	18	3,163	2,684	749

° Light.

## Meteorological data for Huron, Dak., in 1887—Continued.

Date.	Mean daily tem- pera- ture.	Dew point.	Rela- tive hu- mid- ity.	Wind.	Clouds.	Rain.	Frosts.	Posi- tive tem- pera- ture (T -43° F.).	Sum of daily tem- peratures.		
									All.	All above 43° F.	All posi- tive (tem- pera- ture above 43° F.).
1887.	° F.	° F.	Per ct.	Miles.	Per ct.	In.	Date.	° F.	° F.	° F.	° F.
May 29	63	39	46	421	40	Tr.	.....	20	3,226	2,747	769
30	53	43	70	469	67	.....	.....	10	3,279	2,800	779
31	56	46	69	237	53	.....	.....	13	3,335	2,856	792
June 1	61	44	59	212	43	.....	.....	18	3,396	2,917	810
2	65	51	64	316	100	.....	.....	22	3,461	2,982	832
3	59	49	72	360	57	.43	.....	16	3,520	3,041	848
4	56	40	60	190	0	.....	.....	13	3,576	3,097	861
5	70	54	60	371	0	.....	.....	27	3,646	3,167	888
6	83	59	47	441	7	.....	.....	40	3,729	3,250	928
7	70	62	77	234	67	.48	.....	17	3,799	3,320	945
8	67	54	65	119	37	.....	.....	24	3,866	3,387	969
9	70	58	68	141	63	.....	.....	17	3,936	3,457	986
10	69	66	89	276	98	1.13	.....	26	4,005	3,526	1,012
11	74	65	77	183	60	.17	.....	31	4,079	3,600	1,043
12	72	61	72	160	20	Tr.	.....	29	4,151	3,672	1,072
13	74	66	78	196	57	.03	.....	31	4,225	3,746	1,108
14	80	67	66	340	7	.....	.....	37	4,305	3,826	1,140
15	81	69	68	461	0	.....	.....	33	4,386	3,907	1,178
16	77	56	52	301	20	.....	.....	34	4,463	3,984	1,212
17	75	49	45	280	0	.....	.....	32	4,538	4,059	1,244
18	73	50	63	211	23	.02	.....	30	4,611	4,132	1,274
19	71	50	72	249	77	.47	.....	28	4,682	4,203	1,302
20	65	50	62	336	67	.18	.....	22	4,747	4,268	1,324
21	63	43	52	374	33	.....	.....	20	4,810	4,331	1,344
22	60	39	51	348	0	.....	.....	17	4,870	4,391	1,361
23	59	37	51	116	13	.....	.....	16	4,929	4,450	1,377
24	65	52	64	287	40	Tr.	.....	22	4,994	4,515	1,399
25	69	54	62	423	7	.....	.....	26	5,063	4,584	1,425
26	73	62	70	603	53	.....	.....	30	5,136	4,657	1,455
27	77	64	67	438	90	Tr.	.....	34	5,213	4,734	1,489
28	70	63	81	103	100	.92	.....	27	5,283	4,804	1,516
29	73	60	67	290	80	.03	.....	30	5,356	4,877	1,546
30	73	64	76	277	80	.12	.....	30	5,429	4,950	1,576
July 1	72	59	67	131	53	1.38	.....	29	5,501	5,022	1,605
2	63	58	84	214	93	.56	.....	20	5,564	5,085	1,625
3	64	59	84	266	70	.....	.....	21	5,628	5,149	1,646
4	70	57	65	129	17	.....	.....	17	5,698	5,219	1,663
5	72	53	58	190	17	.....	.....	29	5,770	5,291	1,692
6	73	57	61	92	0	.....	.....	30	5,843	5,364	1,722
7	76	58	60	186	60	.....	.....	33	5,919	5,440	1,755
8	76	61	62	280	30	.03	.....	33	5,995	5,516	1,788
9	71	51	56	119	0	.....	.....	28	6,066	5,587	1,816
10	82	56	43	424	33	.....	.....	39	6,148	5,669	1,855
11	68	61	80	304	70	.....	.....	25	6,216	5,737	1,880
12	70	55	64	101	0	Tr.	.....	27	6,286	5,807	1,907
13	81	67	64	321	43	.03	.....	38	6,367	5,888	1,945
14	86	61	48	502	17	.....	.....	43	6,453	5,974	1,988
15	80	65	62	324	43	.....	.....	37	6,538	6,054	2,025

## Meteorological data for Huron, Dak., in 1887—Continued.

Date.	Mean daily tem- pera- ture.	Dew point.	Rela- tive hu- mid- ity.	Wind.	Clouds.	Rain.	Frosts.	Posi- tive tem- pera- ture (T -43° F.).	Sum of daily tem- perature.		
									All.	All above 43° F.	All posi- tive (tem- pera- ture above 43° F.).
1887.	° F.	° F.	Per ct.	Miles.	Per ct.	In.	Date.	° F.	° F.	° F.	° F.
July 16	69	58	69	276	93	-----	-----	26	6,602	6,123	2,051
17	70	56	65	187	60	-----	-----	17	6,772	6,193	2,068
18	72	52	56	174	3	-----	-----	19	6,844	6,265	2,067
19	67	61	81	163	80	-----	-----	24	6,911	6,332	2,111
20	71	60	72	169	80	-----	-----	28	6,982	6,403	2,139
21	67	53	66	166	27	-----	-----	24	7,049	6,470	2,163
22	61	43	55	183	23	-----	-----	18	7,110	6,531	2,181
23	67	57	63	294	57	1.00	-----	24	7,177	6,598	2,205
24	72	58	64	196	3	-----	-----	29	7,249	6,670	2,234
25	73	63	65	477	70	.03	-----	35	7,327	6,748	2,269
26	73	60	69	276	43	-----	-----	30	7,400	6,821	2,299
27	71	60	72	131	40	-----	-----	28	7,471	6,892	2,327
28	74	65	74	233	40	-----	-----	31	7,545	6,966	2,358
29	74	59	62	311	23	-----	-----	31	7,619	7,040	2,389
30	69	57	59	124	3	-----	-----	26	7,688	7,109	2,415
31	72	57	64	236	40	-----	-----	29	7,760	7,181	2,444
Aug. 1	76	60	60	130	20	.01	-----	33	7,836	7,257	2,477
2	70	59	70	349	100	.32	-----	27	7,906	7,327	2,504
3	68	58	74	198	40	.15	-----	25	7,976	7,395	2,529
4	62	55	79	228	67	.04	-----	19	8,068	7,457	2,548
5	64	46	56	132	10	Tr.	-----	21	8,102	7,521	2,569
6	68	54	63	358	37	Tr.	-----	25	8,170	7,589	2,594
7	79	63	61	413	33	.19	-----	36	8,249	7,668	2,639
8	71	58	67	273	33	-----	-----	28	8,320	7,739	2,658
9	66	58	79	257	93	.01	-----	23	8,386	7,805	2,681
10	72	64	76	231	43	.37	-----	29	8,458	7,877	2,710
11	68	51	60	121	13	-----	-----	25	8,526	7,945	2,735
12	63	56	73	206	100	.48	-----	20	8,599	8,008	2,755
13	65	61	85	202	100	1.49	-----	22	8,654	8,073	2,777
14	70	60	71	107	30	-----	-----	27	8,724	8,143	2,804
15	66	59	80	171	57	Tr.	-----	23	8,790	8,209	2,827
16	66	56	72	116	90	.10	-----	23	8,856	8,275	2,850
17	70	56	64	91	3	.05	-----	27	8,926	8,345	2,877
18	67	53	66	109	0	-----	-----	24	8,993	8,412	2,901
19	69	58	70	185	3	-----	-----	26	9,062	8,481	2,927
20	65	58	80	188	50	.47	-----	22	9,127	8,546	2,949
21	68	57	70	197	7	Tr.	-----	25	9,195	8,614	2,974
22	57	44	65	296	50	-----	-----	14	9,252	8,671	2,988
23	51	41	71	146	37	Tr.	-----	8	9,303	8,722	2,996
24	53	40	65	78	60	Tr.	-----	10	9,356	8,775	3,006
25	52	44	76	99	83	.02	-----	9	9,408	8,827	3,015
26	55	45	72	139	100	-----	-----	12	9,463	8,882	3,027
27	63	52	71	332	93	.06	-----	20	9,526	8,945	3,047
28	69	57	67	423	0	-----	-----	26	9,585	9,014	3,073
29	64	59	86	331	67	.04	-----	21	9,659	9,078	3,094
30	67	63	88	248	50	.77	-----	24	9,726	9,145	3,118
31	67	64	92	196	73	1.20	-----	24	9,793	9,212	3,142

\*On and after July 17 the numbers in the column "Sums of all temperatures" must be diminished by 100.

## Meteorological data for Huron, Dak., in 1887—Continued.

Date.	Mean daily temperature.	Dew point.	Relative humidity.	Wind.	Clouds.	Rain.	Frosts.	Positive temperature (T - 43° F.).	Sum of daily temperatures.		
									All.	All above 43° F.	All positive (temperature above 43° F.).
1887.	° F.	° F.	Per ct.	Miles.	Per ct.	In.	Date.	° F.	° F.	° F.	° F.
May 29	63	39	46	421	40	Tr.	-----	20	3,226	2,747	769
30	53	43	70	469	67	-----	-----	10	3,279	2,800	779
31	56	46	69	237	53	-----	-----	13	3,335	2,856	792
June 1	61	44	59	212	43	-----	-----	18	3,396	2,917	810
2	65	51	64	316	100	-----	-----	22	3,461	2,982	832
3	59	49	72	360	57	.43	-----	16	3,520	3,041	848
4	56	40	60	190	0	-----	-----	13	3,576	3,097	861
5	70	54	60	371	0	-----	-----	27	3,646	3,167	888
6	83	59	47	441	7	-----	-----	40	3,729	3,250	928
7	70	62	77	234	67	.48	-----	17	3,799	3,320	945
8	67	54	65	119	37	-----	-----	24	3,866	3,387	969
9	70	58	68	141	63	-----	-----	17	3,936	3,457	986
10	69	66	89	276	93	1.13	-----	26	4,005	3,526	1,012
11	74	65	77	183	60	.17	-----	31	4,079	3,600	1,043
12	72	61	72	160	20	Tr.	-----	29	4,151	3,672	1,072
13	74	66	73	196	57	.03	-----	31	4,225	3,746	1,103
14	80	67	66	340	7	-----	-----	37	4,305	3,826	1,140
15	81	69	68	461	0	-----	-----	38	4,386	3,907	1,178
16	77	56	52	301	20	-----	-----	34	4,463	3,984	1,212
17	75	49	45	280	0	-----	-----	32	4,538	4,059	1,244
18	73	59	63	211	23	.02	-----	30	4,611	4,132	1,274
19	71	59	72	249	77	.47	-----	28	4,682	4,203	1,302
20	65	50	62	336	67	.18	-----	22	4,747	4,268	1,324
21	63	43	52	374	33	-----	-----	20	4,810	4,331	1,344
22	60	39	51	348	0	-----	-----	17	4,870	4,391	1,361
23	59	37	51	116	13	-----	-----	16	4,929	4,450	1,377
24	65	52	64	287	40	Tr.	-----	22	4,994	4,515	1,399
25	69	54	62	423	7	-----	-----	26	5,063	4,584	1,425
26	73	62	70	603	53	-----	-----	30	5,136	4,657	1,455
27	77	64	67	433	90	Tr.	-----	34	5,213	4,734	1,489
28	70	63	81	103	100	.92	-----	27	5,283	4,804	1,516
29	73	60	67	290	80	.03	-----	30	5,356	4,877	1,546
30	73	64	76	277	80	.12	-----	30	5,429	4,950	1,576
July 1	72	59	67	131	53	1.38	-----	29	5,501	5,022	1,605
2	63	58	84	214	93	.56	-----	20	5,564	5,085	1,625
3	64	59	84	266	70	-----	-----	21	5,628	5,149	1,646
4	70	57	65	129	17	-----	-----	17	5,698	5,219	1,663
5	72	53	58	190	17	-----	-----	29	5,770	5,291	1,692
6	73	57	61	92	0	-----	-----	30	5,843	5,364	1,722
7	76	58	60	186	60	-----	-----	33	5,919	5,440	1,755
8	76	61	62	280	30	.03	-----	33	5,995	5,516	1,788
9	71	51	56	119	0	-----	-----	28	6,066	5,587	1,816
10	82	56	43	424	33	-----	-----	39	6,148	5,669	1,855
11	68	61	80	304	70	-----	-----	25	6,216	5,737	1,880
12	70	55	64	101	0	Tr.	-----	27	6,286	5,807	1,907
13	81	67	64	321	43	.03	-----	38	6,367	5,888	1,945
14	86	61	48	502	17	-----	-----	43	6,453	5,974	1,983
15	80	65	62	324	43	-----	-----	37	6,533	6,054	2,025

## Meteorological data for Huron, Dak., in 1887—Continued.

Date.	Mean daily tem- pera- ture.	Dew point.	Rela- tive hu- mid- ity.	Wind.	Clouds.	Rain.	Frosts.	Posi- tive tem- pera- ture (T -43° F.).	Sum of daily tem- perature.		
									All.	All above 43° F.	All posi- tive (tem- pera- ture above 43° F.).
1887.	°F.	°F.	Per ct.	Miles.	Per ct.	In.	Date.	°F.	°F.	°F.	°F.
July 16	69	58	69	276	93	-----	-----	26	6,602	6,123	2,051
17	70	56	65	167	60	-----	-----	17	6,772	6,193	2,068
18	72	52	56	174	8	-----	-----	19	6,844	6,265	2,087
19	67	61	81	163	80	-----	-----	24	6,911	6,332	2,111
20	71	60	72	169	80	-----	-----	28	6,982	6,403	2,139
21	67	53	66	166	27	-----	-----	24	7,049	6,470	2,163
22	61	43	55	183	23	-----	-----	18	7,110	6,531	2,181
23	67	57	63	294	57	1.09	-----	24	7,177	6,598	2,205
24	72	58	64	196	8	-----	-----	29	7,249	6,670	2,234
25	78	63	65	477	70	.03	-----	35	7,327	6,748	2,269
26	73	60	69	276	43	-----	-----	30	7,400	6,821	2,299
27	71	60	72	131	40	-----	-----	28	7,471	6,892	2,327
28	74	65	74	263	40	-----	-----	31	7,545	6,966	2,358
29	74	59	62	311	23	-----	-----	31	7,619	7,040	2,389
30	69	57	59	124	8	-----	-----	26	7,688	7,109	2,415
31	72	57	64	266	40	-----	-----	29	7,760	7,181	2,444
Aug. 1	76	60	60	180	20	.01	-----	33	7,836	7,257	2,477
2	70	59	70	349	100	.32	-----	27	7,906	7,327	2,504
3	68	58	74	198	40	.15	-----	25	7,976	7,395	2,529
4	62	55	79	223	67	.04	-----	19	8,068	7,457	2,548
5	64	46	56	132	10	Tr.	-----	21	8,102	7,521	2,569
6	68	54	63	358	37	Tr.	-----	25	8,170	7,589	2,594
7	79	63	61	413	33	.19	-----	36	8,249	7,663	2,639
8	71	58	67	273	33	-----	-----	28	8,320	7,739	2,658
9	66	58	79	257	98	.01	-----	23	8,386	7,805	2,681
10	72	64	76	231	43	.87	-----	29	8,458	7,877	2,710
11	68	51	60	121	13	-----	-----	25	8,526	7,945	2,735
12	63	56	78	206	100	.48	-----	20	8,599	8,008	2,755
13	65	61	85	202	100	1.49	-----	22	8,654	8,073	2,777
14	70	60	71	107	30	-----	-----	27	8,724	8,143	2,804
15	66	59	80	171	57	Tr.	-----	23	8,790	8,209	2,827
16	66	56	72	116	90	.10	-----	23	8,856	8,275	2,850
17	70	56	64	91	8	.05	-----	27	8,926	8,345	2,877
18	67	53	66	109	0	-----	-----	24	8,993	8,412	2,901
19	69	58	70	185	3	-----	-----	26	9,062	8,481	2,927
20	65	58	80	188	50	.47	-----	22	9,127	8,546	2,949
21	68	57	70	197	7	Tr.	-----	25	9,195	8,614	2,974
22	57	44	65	296	50	-----	-----	14	9,252	8,671	2,988
23	51	41	71	146	37	Tr.	-----	8	9,303	8,722	2,996
24	53	40	65	78	60	Tr.	-----	10	9,356	8,775	3,006
25	52	44	76	99	33	.02	-----	9	9,408	8,827	3,015
26	55	45	72	139	100	-----	-----	12	9,463	8,882	3,027
27	63	52	71	332	93	.06	-----	20	9,528	8,945	3,047
28	69	57	67	423	0	-----	-----	26	9,595	9,014	3,073
29	64	59	86	381	67	.04	-----	21	9,659	9,078	3,094
30	67	63	88	248	50	.77	-----	24	9,726	9,145	3,118
31	67	64	92	196	73	1.20	-----	24	9,793	9,212	3,142

<sup>a</sup>On and after July 17 the numbers in the column "Sums of all temperatures" must be diminished by 100.

## Meteorological data for Huron, Dak., in 1887—Continued.

Date.	Mean daily tem- pera- ture.	Dew point.	Rela- tive hu- mid- ity.	Wind.	Clouds.	Rain.	Frosts.	Posi- tive tem- pera- ture (T -43° F.).	Sum of daily tem- perature.		
									All.	All above 43° F.	All posi- tive (tem- pera- ture above 43° F.).
1887.	°F.	°F.	Per ct	Miles.	Per ct.	In.	Date.	°F.	°F.	°F.	°F.
Sept. 1	68	61	80	119	90	Tr.	.....	25	9,861	9,280	3,167
2	70	63	79	171	53	.....	.....	27	9,931	9,350	3,194
3	67	60	78	233	53	.....	.....	24	9,998	9,417	3,218
4	67	59	79	298	80	.....	.....	24	10,065	9,484	3,242
5	74	65	74	330	20	.04	.....	31	10,139	9,558	3,273
6	68	55	67	289	3	Tr.	.....	25	10,207	9,626	3,298
7	59	47	68	140	0	Tr.	.....	16	10,268	9,685	3,314
8	73	57	60	440	43	.....	.....	30	10,339	9,758	3,344
9	52	39	63	300	0	.....	.....	9	10,391	9,810	3,353
10	50	46	86	159	83	.11	.....	7	10,441	9,860	3,360
11	62	56	82	313	70	.....	.....	19	10,503	9,922	3,379
12	62	56	80	382	67	.....	.....	19	10,565	9,984	3,398
13	55	34	52	411	13	.....	.....	12	10,620	10,039	3,410
14	55	38	59	151	33	.....	.....	12	10,675	10,094	3,422
15	53	36	59	172	33	Tr.	.....	10	10,728	10,147	3,432
16	63	45	53	586	3	.....	.....	20	10,791	10,210	3,452
17	64	52	66	359	67	Tr.	.....	21	10,855	10,274	3,473
18	66	51	59	285	47	.....	.....	23	10,921	10,340	3,496
19	70	59	69	545	63	.....	.....	17	10,991	10,410	3,513
20	67	53	64	355	73	.....	.....	24	11,058	10,477	3,537
21	53	41	67	135	70	Tr.	.....	10	11,111	10,530	3,547
22	46	36	71	225	47	.....	.....	3	11,157	10,576	3,550
23	45	28	55	230	43	Tr.	23	2	11,202	10,621	3,552
24	58	42	57	248	3	.....	.....	15	11,260	10,679	3,567
25	54	35	54	83	57	.....	.....	11	11,314	10,733	3,578
26	60	45	63	311	40	Tr.	.....	17	11,374	10,793	3,595
27	49	41	73	365	67	.....	.....	6	11,423	10,842	3,601
28	49	33	58	61	0	.....	.....	6	11,472	10,891	3,607
29	53	38	62	74	0	.....	.....	10	11,525	10,944	3,617
30	53	39	66	158	3	.....	.....	10	11,578	10,997	3,627

## MAIZE.

The record of the plantings and general condition of the corn for the season of 1888 is taken from the station Bulletin No. 9 by Prof. Luther Foster, director and agriculturist, and is as follows:

The corn experiment embraced a set of 39 plats, each containing 60 rows 24 hills in length. Thirty-three of these plats were planted with different varieties of corn, 18 of Dent and 15 of Flint, the rest being used for experiments in deep and shallow cultivation.

On the first 33 plats the planting began on the 7th and 8th days of May. Two rows of each plat were planted every day for thirty consecutive working days.

It may, perhaps, be unnecessary to state that these daily plantings were made with the object of determining the corn growing season, when germination begins, and the extreme length of planting time.



*Preparation of soil.*—The land used is a sandy loam, with a sub-soil of clay, and slopes slightly to the northwest. It was plowed the previous August to a depth of 6 inches, and thoroughly harrowed in the spring just before planting. It had produced two crops of small grain, and had never been manured.

*Planting.*—The rows were made with a marker 3 feet 6 inches each way. Part of the corn was dropped by hand and covered with the hoe, the rest being put in with hand planters. Of the Dent corn, the hills contained 3 and 4 grains; of the Flint, 4 and 5.

*The stand.*—The early part of the season was not favorable for corn growing, being cold and wet. The coming up was quite irregular, from six to ten days frequently elapsing between the appearance of the first and last hills in a row. This was especially true of the first fifteen days' planting.

The stand in general was poor, resulting in part from unfavorable weather and bad seed, but principally from the work of ground squirrels. This latter evil was the most persistent and damaging one with which the corn experiment had to contend. The per cent taken depended upon location of the variety, whether more or less remote from the unbroken prairie. Notwithstanding all efforts to destroy the squirrels, the damage done was very great. For several successive days previous to planting poisoned corn was placed in every squirrel hole that could be found. This was done not only on the experiment ground, but also on the whole 80 acres and on the edges of the land immediately surrounding it. This work, reenforced with the trap and shotgun, was continued throughout the whole planting season.

*Cultivation.*—All the plats were given four different cultivations, a six-shovel corn plow and a double spring-tooth cultivator being used for the purpose. In addition to this they were twice hoed. Cultivation began on the 11th day of June and ended on the 17th day of July.

*General remarks.*—It was observed in all the plats that the earlier plantings grew larger and stronger than the after ones and that the silks and tassels made their appearance more regularly.

The ears of nearly all varieties of the Flint corn were infested with a species of worm. These did but little damage beyond marring the appearance of the ears. The Dents were not disturbed by the worms.

Immediately after the killing frost on the night of September 11 the corn on all the plats was cut and shocked. It was allowed to stand a few weeks before husking.

The results of a single season's work are only entitled to the public attention as showing the scope of the experiment undertaken.

Definite results of any practical value to the farmer can only be obtained by a continuance of the same experiment under a system of careful observations extending through a number of years. Of this a beginning has been made.

*Tabulated statement.*—In the following table that date of planting is taken which shows the least number of days from time of planting to maturity. The first seven to ten days planting came up and matured at the same time, while the coming up of the rest varied quite regularly with the time of planting.

The items in the columns headed "Up," "In tassel," "In silk,"

"Matured," and "Days to mature" apply only to the planting up to and including the date in the first column. The items in the other columns apply to the whole piece.

The per cent of corn standing and that taken by squirrels was made from actual daily counts of hills.

In computing the yield the corn was weighed instead of measured.\*

*Experiments of 1888 in planting corn at Brookings, S. Dak.*

[First killing frost, 1888, September 12, a. m.]

Variety.	Date of plant- ing.	Date of sprout- ing.	Date of tassel- ing.	Date of silking.	Date of matur- ing.	Days to ma- ture.	Sums of posi- tive (T-43° F.), plant- ing to matur- ing.	Yield per acre of shelled corn.
Dents:							° F.	Bush.
White Rustler .....	May 14	June 5	July 20	July 30	Sept. 4	118	2,556	24½
Austin's Calico .....	do	do	July 21	July 31	Sept. 10	119	2,692	27½
Dakota Yellow .....	May 13	June 4	July 18	do	do	120	2,696	24
Davis's White .....	May 14	June 6	July 23	July 30	Sept. 11	121	2,711	42
Hickory King .....	do	June 5	Aug. 16	Sept. 11		Silk.		
Chester County Mammoth .....	do	June 4	July 20	Aug. 11		Milk.		
Illinois Premium .....	do	June 5	Aug. 1	Aug. 10		Soft.		
Austin's Yellow .....	May 16	June 6	July 25	Aug. 1	Sept. 11	118	2,708	29
Davis's Yellow .....	do	do	July 21	do	Sept. 8	115	2,641	24
Edmund's Premium .....	do	June 8	July 25	Aug. 4		Soft.		31½
Pride of the North .....	do	June 4	July 18	July 27	Sept. 11	118	2,708	21½
Clearance Yellow .....	May 12	June 5	July 24	Aug. 10		Soft.		
Watson's Yellow .....	May 16	June 6	July 28	do		Fair.		
Improved Leaming .....	May 15	do	Aug. 1	do		Poor.		
Dakota Gold Coin .....	May 16	June 7	July 23	July 31	Sept. 6	113	2,601	27
Golden Beauty .....	May 15	do	Aug. 13	Aug. 22		Milk.		
Bloody Butcher .....	May 16	June 6	July 20	Aug. 4	Sept. 11	118	2,708	15
North Star .....	May 18	June 5	July 24	Aug. 1	Sept. 8	113	2,640	21½
Flints:								
Smut Nose .....	May 15	June 4	July 14	July 26	Aug. 20	107	2,187	37½
Compton's Early .....	May 14	June 6	July 17	July 31	Aug. 28	106	2,410	27
Top Over .....	May 12	do	July 19	Aug. 2	Sept. 2	118	2,527	28
Early Canada .....	May 17	do	July 23	do	Sept. 11	117	2,708	17
Self Husking .....	May 16	do	July 16	July 27	Sept. 2	109	2,505	45
Early Six Weeks .....	May 15	June 5	July 19	July 26	Aug. 19	96	2,162	15½
Chadwick .....	May 17	June 7	July 16	do	Aug. 30	106	2,453	24½
Mandan Indian .....	do	do	July 11	July 18	Aug. 15	90	2,071	20
Longfellow .....	May 15	June 6	July 23	Aug. 2	Sept. 10	118	2,699	18
Minnesota White .....	May 16	do	do	do	Sept. 6	113	2,601	27½
Mercer .....	do	do	July 16	July 26	Aug. 27	108	2,371	37
Waushakum .....	May 17	do	July 20	July 31	Sept. 11	117	2,708	36
Silver White .....	May 16	June 4	do	July 30	do	118	2,708	27
King Philip .....	do	June 8	July 26	Aug. 2	do	118	2,708	9½
Angel of Midnight .....	May 13	June 7	July 23	July 30	Sept. 1	111	2,504	34½

\* I regret not to be able to state the source whence the seed was obtained and the climatic peculiarities under which it was raised. According to Linsser's laws this must decide as to the behavior of the seed and plant in a new climate. I know, however, that some of the varieties had been raised in previous years in the neighborhood of Brookings, S. Dak.—C. A.

In comparing the maize experiments at Brookings with the climate of that region, I shall use the record of the Signal Service station at Huron, S. Dak. (lat. 44.3° N.; long. 98.1° W.; altitude above sea level, 1,300 feet), which is 70 miles west of Brookings, and the general meteorological tables for Huron as calculated for this agricultural usage are appended to this table of agricultural experiments.

*Meteorological data for Huron, Dak., in 1888.*

Date.	Mean daily temperature.	Dew point.	Relative humidity.	Wind.	Clouds.	Rain.	Frosts.	Temperature -48° F.	Sums of temperatures.		
									All.	Rejecting all below 48° F.	All positive (temperature -48° F.).
1888.	° F.	° F.	P. ct.	Miles.	P. ct.	In.	Date.		° F.	° F.	° F.
Apr. 1	31	23	73	303	80	0.0	1	-----	31	0	0
2	34	26	73	144	83	Tr.		-----	65	0	0
3	44	34	68	97	8	.02		-----	109	44	1
4	52	44	74	441	57	.50		-----	161	96	10
5	37	26	66	237	33	.0		-----	198	96	10
6	40	27	64	127	0	.0	6	-----	238	96	10
7	46	29	58	210	13	.0	7	3	284	142	13
8	53	32	55	178	43	.0		-----	337	196	23
9	45	30	81	312	67	.04		-----	382	240	25
10	45	27	55	237	33	.0	10	2	427	285	27
11	36	17	52	273	7	.0	11	-----	462	285	27
12	43	32	59	394	40	.0		-----	510	333	32
13	52	36	57	275	0	.0		-----	562	385	41
14	58	32	44	334	0	.0		-----	620	443	56
15	47	33	63	200	3	.0		-----	667	490	60
16	53	37	59	469	60	.0		-----	720	543	70
17	39	21	55	473	13	.0	17	-----	759	543	70
18	34	20	57	184	37	.0		-----	793	543	70
19	34	19	58	188	0	.0	19	-----	827	543	70
20	49	29	53	318	23	.0	20	6	876	592	76
21	59	35	43	154	70	.0		-----	935	651	92
22	49	36	64	325	63	.0		-----	984	700	98
23	44	23	56	179	60	.0	23	1	1,028	744	99
24	57	31	42	644	40	.0		-----	1,085	801	113
25	56	39	55	698	63	.0		-----	1,141	856	123
26	57	40	58	298	20	Tr.		-----	1,198	913	140
27	42	39	87	364	100	.16		-----	1,240	913	140
28	32	27	81	531	100	.16		-----	1,272	913	140
29	34	27	73	300	100	.0		-----	1,306	913	140
30	37	26	67	159	0	.0	30	-----	1,343	913	140
May 1	40	35	81	335	100	.08		-----	1,383	913	140
2	42	39	90	312	100	.44		-----	1,425	913	140
3	40	35	84	409	100	.22		-----	1,465	913	140
4	45	32	62	247	0	Tr.	4	2	1,510	958	142
5	51	34	56	209	70	.0		-----	1,561	1,009	150
6	46	37	73	347	100	.34		-----	1,607	1,055	153
7	48	37	70	259	70	.06		-----	1,655	1,103	158
8	53	32	50	183	63	.0		-----	1,708	1,156	168
9	57	31	45	195	67	.0		-----	1,765	1,213	182

## Meteorological data for Huron, Dak., in 1888—Continued.

Date.	Mean daily tem- pera- ture.	Dew point.	Rela- tive hu- mid- ity.	Wind.	Clouds.	Rain.	Frosts.	Tem- pera- ture —43° F.	Sums of tempera- tures.		
									All.	Re- ject- ing all below 43° F.	All posi- tive (tem- pera- ture —43° F.).
1888.	° F.	° F.	P. ct.	Miles.	P. ct.	In.	Date.		° F.	° F.	° F.
May 10	56	37	54	261	90	.42	-----	13	1,821	1,269	195
11	47	28	54	416	80	.0	-----	4	1,868	1,316	199
12	41	23	57	352	3	Tr.	12	-----	1,909	1,316	199
13	43	18	44	295	83	Tr.	13	-----	1,952	1,316	199
14	47	17	88	155	50	Tr.	14	4	1,999	1,363	206
15	46	30	57	331	47	.0	-----	3	2,047	1,409	206
16	48	29	55	105	50	Tr.	16	5	2,065	1,457	211
17	42	33	72	139	100	.12	-----	-----	2,137	1,457	211
18	44	32	65	155	87	.04	-----	1	2,181	1,501	212
19	52	43	73	430	73	.22	-----	9	2,233	1,553	221
20	63	51	66	317	63	.0	-----	20	2,296	1,616	241
21	58	50	76	288	100	.84	-----	15	2,354	1,674	256
22	55	48	73	400	100	.92	-----	12	2,409	1,729	268
23	52	44	77	391	100	.0	-----	9	2,461	1,781	277
24	53	45	74	207	67	Tr.	-----	10	2,514	1,834	287
25	58	44	63	79	23	Tr.	-----	15	2,572	1,892	302
26	54	49	83	244	100	.66	-----	11	2,626	1,946	313
27	59	44	62	375	77	.02	-----	16	2,685	2,005	329
28	57	40	56	290	33	.0	-----	14	2,742	2,062	343
29	53	40	59	156	53	.0	-----	12	2,797	2,117	355
30	55	43	65	216	50	.60	-----	12	2,852	2,172	367
31	54	39	63	109	47	Tr.	-----	11	2,906	2,226	378
June 1	51	36	60	206	0	Tr.	-----	8	2,957	2,277	386
2	57	43	62	130	7	Tr.	-----	14	3,014	2,291	400
3	66	53	64	439	67	.0	-----	23	3,060	2,314	423
4	64	53	67	573	77	.0	-----	21	3,144	2,335	444
5	50	41	72	378	70	.02	-----	7	3,194	2,342	451
6	55	43	66	166	50	Tr.	-----	12	3,249	2,354	463
7	73	61	68	541	20	.02	-----	30	3,322	2,384	493
8	69	60	76	496	67	.0	-----	26	3,391	2,410	519
9	54	49	83	508	100	.14	-----	11	3,445	2,521	530
10	63	48	62	234	17	.0	-----	20	3,508	2,541	550
11	61	55	82	176	70	.30	-----	18	3,569	2,559	563
12	70	56	63	182	40	.0	-----	27	3,639	2,586	595
13	75	63	69	228	37	.06	-----	32	3,714	2,613	627
14	74	59	65	153	27	Tr.	-----	31	3,788	2,649	658
15	80	70	75	332	40	.02	-----	37	3,868	2,686	695
16	81	70	71	393	8	.0	-----	33	3,949	2,724	733
17	79	65	65	180	23	.0	-----	36	4,023	2,760	769
18	78	65	68	355	0	.0	-----	35	4,103	2,795	801
19	74	67	78	465	40	Tr.	-----	31	4,180	2,826	832
20	68	56	68	523	73	.0	-----	25	4,248	2,851	857
21	59	48	66	615	57	Tr.	-----	16	4,307	2,867	873
22	61	44	54	528	90	.0	-----	18	4,368	2,885	891
23	61	45	57	436	93	.0	-----	18	4,429	2,903	909
24	62	52	71	299	90	.0	-----	19	4,491	2,922	923
25	62	51	70	108	87	.0	-----	19	4,553	2,941	947
26	57	54	90	339	100	.52	-----	14	4,610	2,955	961
27	62	55	81	104	97	.0	-----	19	4,672	2,974	980

## Meteorological data for Huron, Dak., in 1888—Continued.

Date.	Mean daily tem- pera- ture.	Dew point.	Rela- tive hu- mid- ity.	Wind.	Clouds.	Rain.	Frosts.	Tem- pera- ture —43° F.	Sums of tempera- tures.		
									All.	Re- ject- ing all below 43° F.	All posi- tive (tem- pera- ture —43° F.).
1888.	°F.	°F.	P. ct.	Miles.	P. ct.	In.	Date.		°F.	°F.	°F.
June 28	65	59	84	376	53	.0	-----	22	4,737	2,906	1,002
29	70	65	86	395	70	.02	-----	27	4,807	3,023	1,029
30	82	73	76	346	57	.0	-----	39	4,889	3,062	1,068
July 1 <sup>a</sup>	80	-----	-----	282	-----	.0	-----	37	4,969	3,142	1,105
2	74	-----	-----	278	-----	.0	-----	31	5,043	3,216	1,136
3	66	-----	-----	150	-----	.34	-----	23	5,109	3,282	1,159
4	72	-----	-----	140	-----	Tr.	-----	29	5,181	3,354	1,188
5	76	-----	-----	208	-----	Tr.	-----	33	5,257	3,480	1,221
6	70	-----	-----	346	-----	.26	-----	27	5,327	3,500	1,248
7	70	-----	-----	230	-----	.46	-----	27	5,397	3,570	1,275
8	70	-----	-----	254	-----	.02	-----	27	5,467	3,640	1,302
9	66	-----	-----	123	-----	Tr.	-----	23	5,533	3,706	1,325
10	75	-----	-----	239	-----	Tr.	-----	32	5,603	3,781	1,357
11	82	-----	-----	285	-----	Tr.	-----	39	5,680	3,863	1,396
12	76	-----	-----	267	-----	Tr.	-----	33	5,766	3,939	1,429
13	67	-----	-----	234	-----	.02	-----	24	5,833	4,006	1,453
14	72	-----	-----	101	-----	.02	-----	29	5,905	4,078	1,482
15	68	-----	-----	357	-----	Tr.	-----	25	5,973	4,146	1,507
16	66	-----	-----	130	-----	Tr.	-----	23	6,039	4,212	1,530
17	69	-----	-----	328	-----	.0	-----	26	6,108	4,281	1,556
18	68	-----	-----	273	-----	.0	-----	26	6,176	4,349	1,581
19	69	-----	-----	127	-----	Tr.	-----	26	6,245	4,418	1,607
20	78	-----	-----	368	-----	.0	-----	35	6,323	4,496	1,642
21	77	-----	-----	263	-----	.26	-----	34	6,400	4,573	1,676
22	68	-----	-----	124	-----	Tr.	-----	25	6,468	4,641	1,701
23	70	-----	-----	197	-----	.0	-----	27	6,538	4,711	1,728
24	68	-----	-----	199	-----	.01	-----	25	6,606	4,779	1,753
25	74	-----	-----	167	-----	.19	-----	31	6,680	4,853	1,784
26	73	-----	-----	181	-----	.07	-----	30	6,753	4,926	1,814
27	78	-----	-----	185	-----	Tr.	-----	35	6,831	5,004	1,849
28	76	-----	-----	220	-----	Tr.	-----	33	6,907	5,080	1,882
29	77	-----	-----	227	-----	.70	-----	34	6,984	5,155	1,916
30	78	-----	-----	291	-----	.0	-----	35	7,062	5,233	1,951
31	65	-----	-----	254	-----	.76	-----	22	7,127	5,298	1,973
Aug. 1	70	-----	-----	229	-----	Tr.	-----	27	7,197	5,368	2,000
2	71	-----	-----	227	-----	.01	-----	28	7,268	5,439	2,028
3	74	-----	-----	95	-----	Tr.	-----	31	7,342	5,513	2,059
4	68	-----	-----	205	-----	1.50	-----	25	7,410	5,581	2,084
5	65	-----	-----	180	-----	.48	-----	22	7,475	5,646	2,106
6	64	-----	-----	181	-----	.0	-----	21	7,539	5,710	2,127
7	64	-----	-----	223	-----	.01	-----	21	7,603	5,774	2,148
8	55	-----	-----	404	-----	.32	-----	12	7,658	5,829	2,160
9	56	-----	-----	205	-----	.16	-----	13	7,714	5,885	2,173
10	56	-----	-----	200	-----	.20	-----	13	7,770	5,941	2,186
11	58	-----	-----	123	-----	.0	-----	15	7,828	5,999	2,201
12	59	-----	-----	140	-----	Tr.	-----	16	7,887	6,058	2,217

<sup>a</sup> Hours of observation changed July 15, from 7 a. m., 3 p. m., and 10 p. m. to 8 a. m. and 8 p. m. Mean D. P. and R. H. not known.

## Meteorological data for Huron, Dak., in 1888—Continued.

Date.	Mean daily tem- pera- ture.	Dew point.	Rela- tive hu- mid- ity.	Wind.	Clouds.	Rain.	Frosts.	Tem- pera- ture —43° F.	Sums of tempera- tures.		
									All.	Re- ject- ing all below 43° F.	All posi- tive (tem- pera- ture —43° F.).
1888.	°F.	°F.	P. ct.	Miles.	P. ct.	In.	Date.		°F.	°F.	°F.
Aug. 13	68	-----	-----	407	-----	Tr.	-----	25	7,955	6,126	2,242
14	66	-----	-----	276	-----	.28	-----	23	8,021	6,192	2,265
15	60	-----	-----	69	-----	.88	-----	17	8,060	6,252	2,282
16	64	-----	-----	204	-----	.10	-----	21	8,144	6,316	2,303
17	64	-----	-----	74	-----	Tr.	-----	21	8,208	6,380	2,324
18	63	-----	-----	100	-----	Tr.	-----	20	8,271	6,443	2,344
19	67	-----	-----	84	-----	Tr.	-----	24	8,338	6,510	2,368
20	68	-----	-----	82	-----	.02	-----	25	8,406	6,578	2,396
21	66	-----	-----	185	-----	Tr.	-----	23	8,472	6,644	2,416
22	66	-----	-----	155	-----	Tr.	-----	23	8,538	6,710	2,439
23	71	-----	-----	305	-----	.0	-----	23	8,609	6,781	2,467
24	74	-----	-----	199	-----	.0	-----	31	8,683	6,855	2,498
25	71	-----	-----	129	-----	Tr.	-----	28	8,754	6,926	2,526
26	72	-----	-----	211	-----	Tr.	-----	29	8,826	6,998	2,555
27	70	-----	-----	235	-----	Tr.	-----	27	8,896	7,068	2,582
28	74	-----	-----	126	-----	Tr.	-----	31	8,970	7,142	2,613
29	72	-----	-----	147	-----	.0	-----	29	9,042	7,214	2,642
30	65	-----	-----	287	-----	.0	-----	22	9,107	7,279	2,664
31	54	-----	-----	146	-----	.0	-----	21	9,161	7,338	2,685
Sept. 1	61	-----	-----	159	-----	.0	-----	18	9,222	7,394	2,703
2	66	-----	-----	291	-----	.0	-----	23	9,288	7,460	2,726
3	63	-----	-----	259	-----	Tr.	-----	20	9,351	7,523	2,746
4	56	-----	-----	181	-----	Tr.	-----	13	9,407	7,579	2,759
5	68	-----	-----	501	-----	.0	-----	25	9,475	7,647	2,784
6	71	-----	-----	388	-----	.01	-----	28	9,546	7,718	2,812
7	64	-----	-----	209	-----	.04	-----	21	9,610	7,784	2,833
8	62	-----	-----	207	-----	.0	-----	19	9,672	7,846	2,852
9	63	-----	-----	233	-----	.0	-----	20	9,735	7,909	2,872
10	66	-----	-----	270	-----	.0	-----	23	9,801	7,975	2,895
11	52	-----	-----	286	-----	.0	-----	19	9,853	8,027	2,914
12	48	-----	-----	136	-----	Tr.	12	5	9,901	8,075	2,919
13	65	-----	-----	531	-----	.0	-----	22	9,966	8,140	2,941
14	58	-----	-----	442	-----	.06	-----	15	10,024	8,198	2,956
15	52	-----	-----	308	-----	.06	-----	9	10,076	8,250	2,965
16	46	-----	-----	269	-----	Tr.	16	3	10,122	8,296	2,968
17	47	-----	-----	153	-----	Tr.	17	4	10,169	8,343	2,972
18	48	-----	-----	127	-----	Tr.	18	5	10,217	8,491	2,977
19	60	-----	-----	291	-----	Tr.	-----	17	10,277	8,551	2,994
20	64	-----	-----	157	-----	.02	-----	21	10,341	8,615	3,015
21	61	-----	-----	100	-----	Tr.	-----	18	10,402	8,676	3,033
22	57	-----	-----	157	-----	Tr.	-----	14	10,459	8,733	3,047
23	60	-----	-----	256	-----	Tr.	-----	17	10,519	8,793	3,064
24	58	-----	-----	351	-----	Tr.	-----	15	10,577	8,851	3,079
25	50	-----	-----	224	-----	Tr.	25	7	10,627	8,901	3,086
26	52	-----	-----	512	-----	.0	-----	9	10,679	8,953	3,095
27	43	-----	-----	228	-----	.0	-----	0	10,722	8,996	3,095
28	43	-----	-----	78	-----	.0	-----	0	10,765	9,039	3,095
29	45	-----	-----	153	-----	Tr.	29	2	10,810	9,084	3,097
30	54	-----	-----	259	-----	Tr.	30	11	10,864	9,138	3,108

*Experiments in 1890 in planting corn at Brookings, S. Dak.*

[Experiment Station Bulletin No. 24.]

Variety.	Dates of planting.	Dates matured.	Days to mature.	Yield per acre shelled corn.
<b>Dents:</b>				<i>Bushels.</i>
Loveland .....	May 17	Aug. 24	100	33.5
Hughson .....	do	Sept. 10	116	29.2
Davis White .....	do	(a)	-----	32.4
Queen of the North.....	do	(a)	-----	30.8
Dakota Dent .....	do	(a)	-----	21.8
Dakota King .....	May 19	Sept. 12	116	33.6
Gold Coin .....	do	do	116	34.2
<b>Flints:</b>				
Squaw .....	May 17	Sept. 5	111	35.4
Pride of Dakota.....	do	do	111	26.2
Mandan Indian.....	May 23	Sept. 1	101	26.4
Hudson Bay .....	do	(a)	-----	24.1
Mercer .....	June 8	Sept. 15	104	22.1
King Philip .....	May 17	Sept. 12	118	24.1
Compton's Early .....	May 23	Sept. 3	103	20.0
Early Six Weeks.....	do	do	103	24.3
Landreth's Extra Early.....	May 17	Sept. 12	118	32.6
Early Canada .....	May 23	do	112	30.5
Blue Blade .....	May 17	do	118	22.3
Smut Nose .....	do	Sept. 5	111	25.8
Self-Husking.....	May 23	Sept. 6	106	23.8
Chadwick .....	May 16	Sept. 1	108	25.3

\* Some frosted.

NOTES.—First killing frost 1890, September 13, a. m.

The data for 1890 given in this table came to hand too late to allow of preparing the corresponding meteorological table.—C. A. June 30, 1891.

**MAIZE.****INDIANA.**

From experiments in planting maize, made at the Indiana Agricultural Experiment Station (see Agr. Sci., Vol. III, p. 192), the following results were deduced:

Planting on May 1 gave a loss at harvest of 5.47 bushels per acre; planting on May 21 gave a gain of 0.31 bushels per acre.

Deep plowing in 1886 and 1888 gave an increase over shallow plowing of 2.4 bushels per acre, and 0.1 bushel in 1888.

Deep culture with a cultivator of 3 to 4 inches gave better results than a shallow culture of from 2 to 3 inches.

As to rate of planting or density of stand, two kernels every 28 inches apart and three kernels every 36 inches apart seem to give the best results for hand planting. For machine planting, the best results were given with stalks 12 and 14 inches apart.



## NEW YORK.

Prof. C. S. Plumb states, as the result of a research made by himself during the summer of 1886 at the New York Agricultural Experiment Station, on the growth of maize and its dependence upon climate, the following conclusions:

(1) That maize makes a positive daily growth upward from the appearance of the plant above ground till the plant has reached its maximum height.

(2) That the variation in the development of the plant from day to day and week to week is not controlled by meteorological conditions, for of two plants that one which is the most backward at the beginning of the season may eventually become the stronger, larger, and more vigorous of the two.

The measures on which these conclusions are based (see Agr. Sci., Vol. III, p. 1) were made day by day upon seven individual plants, and the averages are given in the following table; the date of planting was May 21, 1886, and the dates of sprouting extended from May 31 for plant No. 1 to June 4 for plant No. 7.

Date of observation.	Average height of 7 plants.	Sums for preceding 7 days.		Sunshine duration.	Rainfall.
		Air temperatures.	Soil temperatures.		
	<i>Inches.</i>	<i>° F.</i>	<i>° F.</i>	<i>Days.</i>	<i>Inches.</i>
June 6.....	8	452	517	28	0.76
June 13.....	8	475	572	60	.0
June 20.....	14	494	569	50	.0
June 27.....	23	466	553	46	.40
July 4.....	35	492	658	84	.0
July 11.....	41	528	597	50	.71
July 18.....	47	464	610	53	.73
July 25.....	61	472	602	50	4.93
Total.....		3,838	4,678	421	7.53

The unsteadiness of the growth is very notable. There was a steady increase up to July 4 and then a drop for fourteen days, but growing more rapidly during the last period. When the greatest growth was made in the eighth or last period, the total air and soil temperatures were less than in the fifth period, when great growth was also made. During this last period of greatest growth the rainfall was large, while during the previous period of great growth the rainfall was zero. Evidently it needs a peculiar combination of rainfall, temperature, and sunshine to bring about the rapid growth. According to Frear, the very rapid growth of plants observed immediately after rainfall is largely due to a simple expansion of the cells with water.

Although a soil gains some nitrogen from the air as brought down

by the rain water, yet it loses a large quantity by the drainage water, which is, of course, richer in nitrogen than the rain. In 1886 and 1887 Berthelot determined by measurement that the nitrogen carried from the soil by drainage water is nearly ten times that brought to the soil by rain water. It is therefore economical to return this drainage water to the field, as far as possible, and thus return with it the nitrogen which has at great expense been given, in the shape of fertilizers, to the field by the farmer. (Agr. Sci., Vol. III, p. 35.)

#### MISSOURI.

Dr. P. Schweitzer, of the Missouri Agricultural Experiment Station, publishes in Bulletin No. IX an elaborate study of the chemical changes that go on in the various parts of the maize plant at different stages of growth. The plant takes up nearly all the ash ingredients during the first stages of growth. The more ash constituents a plant takes up over and above its needs the quicker is its development finished and the smaller is the crop. The young plant takes up nitrogen with extraordinary avidity, and contains a considerable quantity of it. The crop of corn from an acre of land removes therefrom 219 pounds of ash and 135 pounds of nitrogen. The ears in this crop alone contain 52 pounds of ash and 86 pounds of nitrogen. (Agr. Sci., Vol. IV, p. 84.)

#### PENNSYLVANIA.

The relation between meteorological conditions and the development of corn is elaborately presented by Messrs. Frear and Caldwell in the annual report for 1888 of the Pennsylvania State College Agricultural Experiment Station, at Harrisburg, Pa. By testing samples of corn at various stages of its growth we obtain not only some idea of the nature of the changes going on in the plant under the influence of the climate and soil, but the records of past seasons on a given variety at a given locality should give us the means of approximately estimating what will be the crop of the present year. For instance, the loss or gain of dry matter is shown in the following table for one variety of corn out of many that were tested at the Pennsylvania Station.

*Dry weight in 1 acre of several varieties of corn at different stages of growth.*

Variety.	Fully tasseled.	Ears filling out.	Kernels begin to glaze.	Mature ears.
	Pounds.	Pounds.	Pounds.	Pounds.
Blount's Prolific .....	2,735	5,289	4,695	2,310
Chester Mammoth .....	3,802	4,337	5,690	3,073
Golden Beauty .....	2,499	3,950	4,619	2,835
Do .....	2,845	3,443	4,636	3,077
Golden Dent .....	2,633	3,825	5,344	2,529

Such tables as these show that the weight of the mature ears at harvest will not differ much from the weight of the whole plant when dried at the stage of full tasseling, the variations from this rule being about 10 per cent above or below for these varieties.

#### ILLINOIS.

The closeness with which corn or maize or other cereals may be planted depends not only upon the quantity of moisture available in the soil, but also upon the ultimate proposed nature of the crop. Thus in experiments made by the Illinois Agricultural Experiment Station, when corn is planted for ensilage one plant to every 3 inches gave the best result. When planting for the grain the thinnest planted plats gave 5,664 and the thickest planted gave 18,932 ears per acre. As to the date of planting, May 4 to May 19 gave the best harvest.

As to mode of planting, hills nor drills nor fertilizers gave any strongly marked differences.

As to pruning the roots, the pruned and unpruned showed no special difference in regard to size, vigor, date, or yield of harvest. (Agr. Sci., Vol. II, p. 162.)

The development of corn from week to week during the growing season has been studied by Thomas F. Hunt at the University of Illinois Agricultural Experiment Station, at Champaign. He states that the same 18 varieties of corn have been grown at this institution during each of the years 1887, 1888, and 1889, the same varieties being always grown on the same plats and the seed obtained from the same source. The average yield of air-dried corn per acre for the 18 varieties was 29.4 bushels in 1887, 83.2 bushels in 1888, and 66 bushels in 1889. Meteorological conditions appear to have been largely, if not solely, the causes of these differences in the yield. In 1889 measures were made weekly on three plants on each hill of Edmund's Golden Dent, which is usually an early variety, but this year matured late, owing to the low temperature. The corn was planted four kernels to a hill on the 4th of May; it sprouted on the 20th of May, the soil having been very dry, and made slow growth to June 10, on account of the low temperature. The following table shows the weight of dried substance in a hill of three plants of uniform character:

Date of cutting.	Average weight.	Remarks.
	<i>Grams.</i>	
June 10 .....	0.51	
June 17 .....	2.48	
June 25 .....	10.11	
July 1 .....	33.84	
July 8 .....	75.46	
July 15 .....	197.99	
July 22 .....	322.91	Tassels showing; not in bloom; no silk.
July 30 .....	408.07	All in tassel; in bloom; in silk.
August 5 .....	589.10	
August 12 .....	681.55	Silks dead or partly so.
August 19 .....	724.449	Soft milk stage.
August 26 .....	949.53	Milk stage or passed.
September 2 .....	906.22	Mostly glazed.
September 10 .....	1,034.55	Varies from milk stage to ripe.
September 16 .....	1,176.00	All ripe except 1 ear.

Professor Hunt finds that the varieties of corn that mature about September 25 give the largest yields; date of planting has little influence on the yield. Depth of planting and drilling versus hill planting did not affect the yield in 1888 or 1889. The quantity of seed planted was more important than the allotment of the kernels to the hills; preventing the growth of weeds was more important than stirring the soil; pruning of roots injured the crops; shallow-working cultivators gave better results than deep-working; commercial fertilizers did not materially increase the yield, but stable manures did so. (Agr. Sci., Vol. IV, p. 184.)

### MAIZE AND PEAS.

#### NEW YORK.

Sturtevant (1884) gives the results of two years' observations (1883 and 1884) at the experiment station, Geneva, N. Y., on the thermal constants of many varieties of maize and peas. He observed both the temperature of the soil and the air, and takes for his computations always the first plant which sprouted, bloomed, or ripened. Observations of 128 varieties of maize, four hills to each variety, gave an extreme variation of 19 days between the blooming of the first and last hill, the average interval being 4.92 days. As Sachs adopts 49.1° F. as the lowest temperature at which maize will germinate, and Köppen gives 49.2° F., therefore Sturtevant adopts 50° F., and considers that any observed temperature, less 50° F., leaves a remainder that is nearly proportional to the growth of maize at that temperature. A similar lower limit of 44° F. is adopted for the growth of the pea. He notes that in 1885, by trial at this experiment station, the "Chester County Mammoth Corn" germinated

in 430 hours at a temperature which was between 37° and 42°, averaging above 40° F., while the Waushakum variety required 460 hours at the same temperature.

Sturtevant calculates the sum total of temperatures by three methods, a comparison of which is instructive. His results are in the following table:

*Thermal constants for maize at Geneva, N. Y., from germination to blooming.*

Variety and subvariety.	Sums of all mean daily air temperatures.	Sums of all positive mean daily air temperatures, less 50° F.	Sums of all positive means of temperature of air, and soil at 1 foot depth, less 50° F.
<b>Sweet corn:</b>	° F.	° F.	° F.
Crosby's Early .....	3,595	845	937
Daily Dutton .....	3,181	756	859
Egyptian .....	4,342	1,042	1,132
Stowell's Evergreen .....	4,400	1,050	1,147
<b>Flint corn:</b>			
Forty Days .....	3,328	808	854
King Philip .....	3,751	901	965
Rural Thoroughbred .....	4,668	1,118	1,210
Waushakum .....	3,698	808	956
<b>Dent corn:</b>			
Adams Early .....	3,589	839	978
Benton .....	4,187	1,012	1,086
Blount's Prolific .....	4,737	1,162	1,235
Chester County Mammoth .....	5,192	1,342	1,319
Sibley's Pride of the North .....	3,818	943	987

The dates were: Corn planted May 16, 1883, and May 19, 1884; sprouted May 28, 1883, and May 26, 1884; bloomed July 16 to August 8, 1883, and July 16 to August 26, 1884.

*Thermal constants for peas from sprouting to maturity at Geneva, N. Y.*

Variety.	Sums of all mean daily air temperatures.	Sums of all positive mean daily air temperatures, less 44° F.	Sums of all positive means of air and soil temperatures at 1 foot depth, less 44° F.
	° F.	° F.	° F.
American Wonder .....	3,516	1,150	1,236
Champion of England .....	4,516	1,377	1,506
Kentish Invicta .....	3,674	1,176	1,501
McLean's Advance .....	4,515	1,376	1,520
Premium Gem .....	3,836	1,152	1,250
Telephone .....	4,576	1,408	1,524

Peas planted April 21 and May 12, 1883; April 28, 1884; ripened July 10 to August 6, 1883; July 2 to 28, 1884.

These figures show eccentricities from year to year in the same variety, but the peculiarities of the varieties are much larger than these eccentricities. Sturtevant suggests that actinism has an influence scarcely second to temperature.

### **SORGHUM.**

#### **UNITED STATES.**

W. E. Stone (Agr. Sci., Vol. IV, p. 166) summarizes the results of the experiments on sorghum published by Wiley in Bulletins Nos. 20 and 26, Division of Chemistry, United States Department of Agriculture. He says the controlling conditions of success are suitable soil and climate, proximity of cane fields to the factory, supply of water and fuel, cost of the factory, and careful control of its operations. All experience points to southern central Kansas as the region best adapted to the growth of the sorghum. In New Jersey the plant, which at one time gave hopeful results, has deteriorated until it has become a worthless variety for sugar making, or even for the production of sirup. In Louisiana the results were disappointing in seasons which were the most favorable for the sugar cane. At Conway Springs, Kans., the average percentage of cane sugar was 12.42 in 1888 and 11.98 in 1889, being the best record of all.

In general, with a normal amount of moisture, and other things being equal, the percentage of sugar depends upon the amount of sunshine received; excessive moisture is detrimental, as it directly interferes with nutrition and indirectly as being accompanied by cloudiness.

A mean temperature of 70° F. is the minimum necessary to mature early varieties. The semiarid region south of the isotherm of 70° F. in the southwest central portion of the United States is best adapted to the growth of sorghum. East of the Mississippi the recurrence of wet seasons renders the crop uncertain. A permanently improved plant can certainly be developed from existing varieties by selection.

### **OATS.**

#### **KANSAS.**

During the drought of 1890 the Kansas Agricultural Experiment Station secured the following comparative observations: On unplowed land the yield of listed oats was 2.4 bushels per acre better than on plowed land; the yield of drilled oats was 1 bushel per acre better on unplowed land; the yield of oats cultivated into the soil was 5 bushels per acre better on the unplowed land; the oats sown broadcast on plowed land gave the same results as the oats cultivated into unplowed land; the oats plowed under gave the least harvest of

all the five methods of seeding, while the drilled oats gave the best. This superiority of the drilled oats is probably due to the fact that the instrument pressing firmly upon the soil makes a firm bed at the bottom of the drill, into which the seed is dropped. In a loose soil oats run to straw, but in a firm soil they give a larger percentage of grain. In the present case oats drilled into unplowed land gave 34.5 bushels per acre, but when plowed under gave 21.6 bushels, or a loss of 35 per cent.

As to the time of harvesting oats, they should be cut early, viz, in the dough stage, if the straw is wanted for feed; but if the grain alone is wanted they should be allowed to mature, notwithstanding the fact that there is then a greater loss due to the beating out or dropping of the grain in harvesting. (Agr. Dept. Exp. Sta. Record, Vol. II, p. 222.)

#### OHIO.

In Bulletin No. 3 of Volume III of the Ohio Agricultural Experiment Station it is shown that the experiments of 1889 indicate that more cultivation should be given in dry seasons than in wet seasons.

#### **FREEZING OF PLANTS AND SEEDS.**

Detmer (1887), with reference to the effect of low temperatures on plants, finds:

(1) Fruits and seeds that have been dried in the air can be exposed for a long time without injury to very low temperatures, but if they have first been swollen with moisture they are destroyed by low temperatures. In the case of wheat exposed to a temperature of  $-10^{\circ}$  C., although it will germinate, still its power of growth is decidedly less than before.

(2) Many plants and parts of plants withstand temperatures below freezing, and many bacteria withstand much lower temperatures; those experimented on by him were not killed by an exposure to temperatures of  $-17^{\circ}$  C.

(3) In accordance with Sach's experiments, he finds many plants which after being frozen survive if they are thawed out in water at low temperatures ( $6^{\circ}$  C.), but not when thawed out in water at  $+17^{\circ}$  C., thus showing the manner in which a warm rain may act injuriously upon a forest.

(4) Certain plants are definitely destroyed by freezing independently of the subsequent thawing, such as the leaves of the begonia.

(5) Experiments have given a negative result as to the question whether any plant, although accustomed to the warmest climate, can be killed by a short exposure to a low temperature which is, however, still above freezing. (See Wollny, X, p. 236.)



## WHEAT.

A detailed study of the relation of low temperatures to the growing of wheat has been made by S. G. Wright, of Indiana, from which I take the following conclusions:

*Sleet.*—When the winter wheat has its blades covered with ice that has fallen as sleet, and after the ice has melted off a microscopic examination shows the cellular structure to be altered, the epidermis is separated from the underlying cells and there is a general disunion of the cells, and when the growing season comes the plants are found to be entirely dead.

*Sudden thawing.*—Wheat plants exposed to a very low freezing temperature in dry air if thawed out slowly are not much injured, but if thawed out rapidly the younger sprouts are completely killed and the older ones subsequently die. The similar rule obtains for the germination of seeds. When frozen seeds were quickly thawed out only 18 per cent germinated, but when slowly thawed out 86 per cent germinated.

*Freezing temperature of the juices of the wheat.*—The juice extracted by pressure from the wheat has a lower freezing point than that of pure water when contained in its original living tissues, but after being extracted by pressure it freezes at an intermediate point below that of pure water. Again, the juice extracted from plants that have been exposed to a low winter temperature withstands freezing better than the juice from plants that have not had such exposure. For example, the juice within the cells was not frozen at  $-13^{\circ}$  C., while that thrust out of the cells froze at  $-6^{\circ}$  C., and in general the power to resist freezing is increased by exposing plants to the ordinary winter temperatures of the open air.

*Method of sowing.*—The best method of sowing wheat in order that it may withstand severe winter weather is (1) to avoid mulching or having any layer of porous material about the roots of the wheat, as experiment shows that this is a decided injury both to the wintering, the after growth, and the harvest. An average depth of seed planting of 1.5 inches is much better than three-fourths inch or 3 inches.

*Range of temperature for germination.*—According to Sachs, the minimum temperature is  $5^{\circ}$  C. and the maximum  $37^{\circ}$  or  $38^{\circ}$  C. According to Haberlandt, the temperature for germination ranges between  $0^{\circ}$  and  $-4.8^{\circ}$  C. at the lower limit and  $31^{\circ}$  to  $37^{\circ}$  C. at the upper limit. Wright's experiments, at a constant temperature of  $39^{\circ}$  C., gave germination successful in forty-eight hours; at a temperature of  $42.5^{\circ}$  C. only a very few seeds could be made to germinate. At a temperature of  $0^{\circ}$  C. the seeds germinated in ten days; hence the extreme range of germinating temperatures for winter wheat of the varieties thus tested in Indiana is from  $0^{\circ}$  to  $42.5^{\circ}$  C. As to the effect

on germination of freezing the seeds just before they were ready to germinate, it was found that seeds soaked until ready to germinate and then kept frozen for a length of time required a longer time to complete the germination than did those that had not been frozen; the retardation increased in proportion to the duration of the freezing, amounting to about twelve days for a freezing of twenty-four days. The percentage of thawed-out seeds that germinated was also smaller in proportion as the duration of the freezing increased, being 44 per cent for a duration of twenty-four days.

*Changes in the seeds produced by frost.*—After the seeds had remained frozen for ten to twelve days a white, glutinous material oozed out at every slight break in the coat of the seed. A microscopic examination showed that the cell wall and starchy protoplasm was almost entirely disorganized, but the starch granules themselves were entirely unaffected. Strange to say, the power of the seeds to germinate was not destroyed by this. (Agr. Sci., Vol. IV, p. 337.)

*Protection from frosts.*—The formation of artificial clouds of smoke for the protection of plants from frost is generally successful, and should be resorted to in critical cases; thus, in a vineyard at Pagny about 3 a. m. of May 13, 1887, when the temperature was 3° F. below freezing, liquid tar was ignited, which had been poured into tin boxes, as also pieces of solid tar. Large clouds of smoke quickly enveloped the vineyard; the fires lasted for about two hours, but the smoke lasted considerably longer. All injury to the plants by frost was entirely prevented. (Agr. Sci., Vol. I, p. 172.)

#### **INJURIES AND BENEFITS DUE TO WIND-BREAKS.**

Protection against the injurious effects of wind may be obtained by the use of wind-breaks, which are usually made by planting a couple of rows of trees on the windward side of the field, or by so arranging the plantation that the hardiest and most vigorous deciduous trees are on the windward side. According to Bulletin No. IX issued by the Cornell University Agricultural Experiment Station, the benefits derived from wind-breaks are the following: Protection from cold, diminution of evaporation from soil and plants, diminution of the number of windfalls, diminution of liability to mechanical injury to trees, retention of snow and leaves, facilitation of outdoor labor, protection of blossoms from severe winds, protection of trees from deformity of shape, diminution of evaporation and drying up of small fruits, diminution of the encroachment of sand or the loss of dry soil or the scattering of rubbish, increased rapidity of maturity of fruits, and encouragement of birds that are beneficial to agriculture.

Among the organisms arrested by wind-breaks and usually reckoned as an injurious climatic influence are the fungi or the spores of fungi.

Jensen has, however, shown that bunt in wheat and smut in oats or barley or rye can be almost wholly prevented by washing the seed before sowing, in water whose temperature is not lower than 130° F. nor higher than 135° F. The sacks to receive the seeds should also be disinfected. Professor Kellerman shows that if the seeds are previously soaked in cold water for eight hours the hot-water wash may have a temperature of 124° to 128°. I infer that the spores of the smut, having been by the winds blown over the field in the ripening period, have stuck to the grains from that time on to the next sowing season. (Agr. Sci., Vol. IV, p. 100.)

#### **THUNDERSTORMS AND OZONE.**

A. L. Treadwell seems to have shown that the souring of milk during thunderstorms can not be attributed to any formation of ozone, and is more likely to be due to the fact that the bacteria causing this souring multiply with unusual rapidity during the warm sultry weather that precedes and accompanies thunderstorms. (Agr. Sci., Vol. V, p. 108.)

#### **PRUNING VERSUS CLIMATE.**

Kraus (1886) in some experiments on pruning hop vines shows first that those that were not pruned had an advantage in the early growth, especially in the cold and wet of June, 1886, in Germany, but in consequence of this precocity the early ones suffered from frost. Those that were early pruned surpassed them in the harvest.

Those that were pruned late gave the smallest harvest, but of the highest quality, the leaves remaining a beautiful green up to the harvest time, while those that were not pruned or those that were late pruned turned dark and soon yellowed.

This explains why for a long time it has been impossible to define exactly the climate that is best for the cultivation of hops, since it is now evident that changes in the pruning, harmonizing with peculiarities of weather or locality, have so great an influence upon the successful cultivation. (See Wollny, X, p. 236.)

#### **WHEAT, TEMPERATURE, AND RAIN IN ENGLAND.**

The wheat harvest of England has been studied by an anonymous writer. (Nature, 1891, vol. 43, p. 569.) I do not know the authorities for his statements as to the character of the harvests from year to year, but reproduce in the following tables the figures given by him as to the general character of the wheat harvests for each year and the corresponding mean temperatures and total rainfall for the months of June, July, and August as observed at the Royal Observatory, at Greenwich. Certain deductions are given by him as to the connection between the harvests and these items of the weather, but a more careful study of the figures convinces me that taken as they stand no infer-

ence can be safely drawn from them which will endure the test of critical examination. Any small selection of years may be made which will seem to support some suggested relation between temperature, rainfall, and crop, but other years will be found to contradict this. In a general way good crops result from hot and dry summers and bad harvests depend upon the large rainfalls rather than on the low temperatures. I have added the column of departures and have computed the probable errors of the averages, the study of which shows that the temperatures of the good harvest seasons are not sufficiently above those of the poor harvest seasons to justify the conclusion that warm seasons are intimately connected with good harvests. If, however, we go into more detail and examine all of the fifty-three years from 1816 to 1888, inclusive, and arrange them by the character of the harvests, we find innumerable contradictions. The study of the rainfall with its probable errors, or rather its probable variability, shows a somewhat stronger argument in favor of the idea that large rainfalls accompany poor harvests, and yet here again the contradictions are too numerous to allow us to suppose that this simple statement expresses exactly any law of nature. Thus the largest rainfall of 1888 and the small rainfall of 1886 both contradict this law. In the notes a few statements are made by the author as to special occurrences which seem to him to explain these anomalous cases, and by hunting through the records a few more notes might have been added so that after leaving out the anomalous cases one might say that the remainder accords well with the idea that dry hot summers give large crops and that heavy rains give poor crops. In general, however, it seems more proper to conclude that we are far from having attained the expression or formula connecting the crops and the weather, and that even if we knew this it would be improper to study the crops of England with reference to the temperature and rainfall at Greenwich, or, indeed, any other single station.

*English wheat harvests and Greenwich weather.*

[Weather in June, July, and August.]

I. SUPERIOR WHEAT HARVESTS.

Year.	Character of harvest.	Temperature.		Rainfall.	
		Ob-served.	Dep.	Ob-served.	Dep.
		° F.	° F.	Inches.	
1775	Plentiful.....	62.0	+0.8	(?)	.....
1779	.....do.....	62.8	+1.1	(?)	.....
1791	Abundant.....	59.5	-1.7	Dry.	.....
1818	Most abundant.....	64.8	+3.1	1.4	-4.8
1819	Fine.....	60.3	-1.9	4.6	-1.1
1820	Productive.....	58.0	-3.2	8.2	+2.5
1825	Early and good.....	62.0	+0.8	3.3	-2.4
1826	Remarkably early and very great.....	64.0	+2.8	5.1	-0.6
1827	Good.....	60.0	-1.2	2.9	-2.8

## English wheat harvests and Greenwich weather—Continued.

## I. SUPERIOR WHEAT HARVESTS—Continued.

Year.	Character of harvest.	Temperature.		Rainfall.	
		Ob-served.	Dep.	Ob-served.	Dep.
		° F.	° F.	Inches.	
1833 <sup>a</sup>	Abundant.....	59.4	-1.8	6.7	+1.0
1834 <sup>b</sup>	Early; very productive.....	62.5	+1.3	11.3	+5.6
1835	Good.....	62.6	+1.4	4.5	-1.2
1840	Fine yield.....	59.8	-1.4	8.9	-1.8
1849	Above the average.....	61.0	-0.2	3.8	-1.9
1851	do.....	61.0	-0.2	7.2	+1.5
1854	Extremely good.....	59.0	-2.2	5.6	-0.1
1857	Above the average.....	63.9	+2.7	6.0	+0.3
1858	do.....	62.5	+1.3	5.7	0.0
1863	Abundant.....	60.3	-0.9	6.6	+0.9
1864	Good.....	59.6	-1.6	2.5	-3.2
1868	Productive.....	64.4	+3.2	4.1	-1.6
1874	Very good.....	60.9	-0.8	6.4	+0.7
1888 <sup>c</sup>	Above the average.....	58.4	-2.8	13.8	+8.1
	Mean of 23 and 20, respectively.....	61.2		5.68	
	Probable errors of these means.....	±0.37		±0.65	

## II. INFERIOR WHEAT HARVESTS.

1789	Very deficient.....	59.7	+0.3	Wet.	-----
1792	Inferior.....	58.3	-1.1	Wet.	-----
1795	Very defective.....	57.8	-1.6	(?)	-----
1800	Bad.....	60.7	+1.3	Wet.	-----
1810	Scanty.....	60.0	+0.6	(?)	-----
1811	Very scanty.....	59.0	-0.4	(?)	-----
1812	Very defective.....	56.0	-3.4	(?)	-----
1816	Very great deficiency.....	55.2	-4.2	8.4	-0.2
1817	Deficient.....	57.4	-2.0	7.9	-0.7
1821	Inferior.....	57.8	-1.6	7.0	-1.6
1823	Deficient.....	57.8	-1.6	7.1	-1.5
1828	Bad.....	60.3	+0.9	12.0	+3.4
1829	Inferior.....	59.0	-0.4	9.4	+0.8
1838	Late; unproductive.....	59.1	-0.3	7.3	-1.3
1839	Damaged.....	59.3	-0.1	7.6	-1.0
1843	Very bad.....	59.5	+0.1	10.6	+2.0
1852	Below the average.....	61.7	+2.3	11.4	+2.8
1853	Bad.....	60.1	+0.7	11.0	+2.4
1860	Very deficient.....	56.7	-2.7	11.6	+3.0
1867	Deficient.....	59.8	+0.4	10.2	+1.6
1873 <sup>d</sup>	Very deficient.....	61.7	+2.3	7.6	-1.0
1875	Very unsatisfactory.....	60.3	+0.9	9.8	+1.2
1876 <sup>e</sup>	Unsatisfactory.....	62.7	+3.3	3.7	-4.9
1877 <sup>e</sup>	do.....	62.0	+2.6	6.0	-2.6
1879	Worst known.....	58.5	-0.9	13.3	+4.7
1880	Deficient.....	60.6	+1.2	7.1	-1.5
1881	do.....	61.1	+1.7	2.9	-0.7
1886 <sup>f</sup>	do.....	61.0	+1.6	4.1	-4.5
	Mean of 23 and of 21, respectively.....	59.4		8.6	
	Probable errors of the means.....	±0.33		±0.54	

<sup>a</sup> May was very dry.

<sup>b</sup> The winter was very mild; the spring very dry.

<sup>c</sup> The winter and early spring were very cold; May was very dry, with much sunshine.

<sup>d</sup> Frost occurred at blooming time.

<sup>e</sup> The spring was cold.

<sup>f</sup> The winter and early spring were very cold; May was very wet.

### SUGAR CROP AND RAIN IN BARBADOS.

Sir R. W. Rawson, as governor of the British colonies at Barbados, published (1874) a colonial report, printed by the house of assembly, giving an elaborate study of the dependence of the cane-sugar crop upon the monthly and annual rainfall. Barbados offers an exceptional opportunity for such study, since the cane is the only staple and is nearly all exported, so that the records of the crop are accessible in the customs' returns. Moreover, the number of rainfall records averaged more than 1 to a square mile, being 178 for the whole island and for a period of about twenty-five years, this remarkable system of observations being due largely to the labors of Dr. R. Bowie Walcott, who still resides in the parish of St. Joseph, and was, in May, 1890, on the occasion of my recent visit to him, still active in collecting rainfall data. To his devotion and Governor Rawson's assistance we owe this unique study of rainfall and sugar crop. It is impossible for me at present to do more than give the accompanying Tables I, II, and III of monthly rainfalls and annual crops. The crops, as given in Tables II and III, in hogsheads, are credited to the years in which they passed through the custom-house. The cane is usually gathered and the sugar and molasses shipped between January and May; after the latter date the fields are newly planted and in eighteen months are again ready for cutting, so that the crop of any year has been grown under the influence of the rain of the preceding year and the latter half of the year preceding that. In the second table I give the dates of the first shipment of sugar each year, thus showing whether the crop was gathered early or late, and also the general character of the crop as credited to that year.

Table III illustrates Governor Rawson's conclusion that the crop of any year is influenced only in a slight degree by the rainfall of that year, but depends upon the rainfall of the preceding year. Thus it is arranged according to the quantity of rainfall, and the crop of the following year is compared with the rain of the current year; the wet years are followed by large crops the next year, while the dry years are followed by small crops; the increase being 10 per cent after a wet year and the decrease being 12 per cent after a dry year.

The general development of the sugar plant is illustrated in the following extract (see p. 33, Rawson's Report) :

The influence of the rainfall in particular months and seasons upon the coming crop is generally felt and admitted, but not known with any certainty. It is believed, writes an experienced agriculturist, that any marked excess of rain during the first six months of the year is injurious both to the crop that is being reaped and to that which is to follow. The cane plant during the early stages of its growth is very hardy and requires but little moisture; the small



early shoots are hard and fibrous, and very different from the large succulent shoots which are afterwards produced and which lengthen into the juicy reed whence the crop is made. In ordinary and favorable years, with light showers during the first six months, the young canes make no marked progress, but the roots are increasing in length and strength, and in the months of July and August the plant begins to sucker, as it is called, and to put out the shoots which form the canes, but these make no great progress in length before the end of August and in September and October, when the rains usually come to their aid at the critical time. They then grow with extreme rapidity, are extremely tender and succulent, and a short spell of dry weather at that time usually does serious mischief. If, however, the first six months of the year are wet, and the young canes are excited to an abnormal rapidity of growth, they are liable to be seriously affected by any interval of dry weather in the middle of the year. Moreover, rainy weather in the reaping season retards the manufacture, and, especially in the black soils which contain an excess of iron variously combined, causes a great loss from the rotting of the canes at the roots.

An illustration of this is afforded by the rainfall and crops of 1860 and the two following years. 1860 was a model year; the rain fell at the right time, and in exactly the average quantity, 57.91 inches, of which 12.46 fell during the first six months. The crop of 1861 would undoubtedly have reached 55,000 hogsheads but for the wet reaping season of that year, in which the rainfall of the first six months was 31.93 inches—6.35 in April, 8.01 in May, and 8.01 in June. The consequence was that the crop only reached 49,745 hogsheads, and although so much rain fell throughout the year (73.82 inches), the following crop of 1862 was only 46,120 hogsheads.\*

In the same manner the heavy rainfall of 1855 (77.31 inches, of which 30.68 fell in the first six months) was followed in 1856 by only a moderate crop (43,077 hogsheads), although the reaping season of that year was most favorable. The result, however, is by no means constant.

The sugar-crop records go back to the year 1806, but the returns are only interesting since 1847, which was the first in which the crop recovered from the effects of emancipation in 1839. Since 1847 there has been a steady increase until the crop has attained nearly twice what it was before emancipation. There has also been a slow increase in acreage of canebrake; the size of the hogsheads has been gradually increasing since 1806; there has been a decided increase in the usage of guanos and other foreign manures; there has also been a very decided improvement in the machinery and processes for crushing the cane and manufacturing the sugar.<sup>a</sup>

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\* Although Governor Rawson was evidently conscious of these progressive changes, and in fact, mentions most of them, yet he does not approximately eliminate their effects by taking the difference between the individual crops and a progressively increasing ideal normal, but takes the difference between the simple average and the individual years; his results, therefore, need to be computed and all the data for this purpose are given in the tables herewith.—C. A.



The average crop divided by the average rainfall of the preceding year shows that each inch of rain corresponds to about 800 hogsheads in the resulting crop; the extreme limits of variations are 713 and 877 hogsheads, so that in general Governor Rawson proposes to predict the crop that will be gathered during the dry season, February to May, each year by simply multiplying the rainfall of the preceding calendar year by 800. The average uncertainties of the crop thus predicted is very small, the extreme error being 28 per cent positive following the wet year 1861 and 4 per cent negative for a certain dry year; therefore as an improvement on this method he adopts the rule of adding 7 per cent for wet years and subtracting 7 per cent for dry years, the average year being that which corresponds to 55 inches of rainfall.

In supplementary calculations Rawson and Walcott show the chances of a good crop as calculated from a large, small, or average rainfall, respectively, for each month of the year, but I do not find that they have at any time compared the crop with the total rainfall for the whole eighteen months or growing period that immediately preceded the crop, which comparison I have therefore made and give in Table III.

From all which it appears that large rains gives large crops, but occasionally much smaller rains do also, so that it may reasonably be suspected that here, as elsewhere, the sunshine must be considered; probably large rains are only of advantage when they occur at such a time that they do not diminish the sunshine and in such a manner that they do not wash the soil too severely.

It would have been desirable to have stated these crops as yields per acre rather than as total crops, but I find no statement of the actual acreage in cane. Rawson gives only the total areas of the six divisions of the island, which sum up 107,000 acres; probably two-thirds of this is planted in sugar cane, so that an inch of annual rainfall corresponds to  $\frac{800}{100000}$ , or one-ninetieth of a hogshead of sugar per acre.

It is, however, more proper to reason upon this matter as follows: Eleven poor crops gave, according to Table I, an average deficit of 15 per cent; 12 good crops gave an average excess of 14 per cent; the average rainfalls were 55.15 and 58.18, respectively. Therefore an increase of 1 inch in rainfall corresponds to a gain of  $\frac{2}{3}$ , or 10 per cent of an average crop.

TABLE I.—*Barbados sugar crop and monthly rainfall.*

Year.	Excess of sugar crop.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.
	<i>Per cent.</i>	<i>Inches.</i>	<i>Inches.</i>	<i>Inches.</i>	<i>Inches.</i>	<i>Inches.</i>	<i>Inches.</i>	<i>Inches.</i>
1868 .....	+29	4.29	1.74	1.93	0.97	1.68	3.45	6.28
1866 .....	+27	3.75	2.75	1.57	1.26	2.74	2.63	6.28
1852 .....	+21	3.30	1.58	1.53	2.17	7.11	2.17	2.49
1871 .....	+20	4.13	2.29	1.07	0.56	0.98	2.71	3.65
1854 .....	+17	2.64	1.95	1.43	1.20	1.33	5.56	5.68
1867 .....	+14	2.68	4.49	0.88	1.64	2.66	10.94	7.50
1858 .....	+13	1.52	1.28	1.40	0.96	2.23	4.54	3.69
1856 .....	+11	1.73	2.18	1.19	0.81	2.94	5.49	2.86
1861 .....	+10	3.49	1.96	2.76	6.35	8.01	9.31	8.28
1862 .....	+ 2	7.60	1.12	0.31	1.12	3.53	7.18	5.39
1865 .....	+ 2	2.36	2.19	1.39	4.13	5.89	9.19	7.35
1855 .....	+ 1	6.96	2.95	1.85	5.49	6.82	6.61	8.00
1851 .....	0	1.62	3.01	1.99	1.58	6.13	5.31	6.63
1853 .....	0	4.04	3.94	2.38	3.38	9.26	5.21	3.89
1860 .....	— 5	2.28	2.85	1.13	2.41	0.66	3.13	3.90
1863 .....	— 6	1.19	3.88	2.26	2.26	0.56	1.62	3.65
1850 .....	— 8	1.14	2.52	0.78	2.96	4.70	10.48	9.01
1859 .....	—12	2.10	2.64	1.22	1.24	3.56	5.68	5.72
1870 .....	—13	3.96	1.35	0.90	0.96	2.80	10.15	5.62
1857 .....	—14	2.63	5.78	2.02	1.54	2.64	5.43	7.14
1849 .....	—15	3.61	2.72	3.90	2.69	2.34	6.63	5.64
1847 .....	—16	2.83	0.95	1.20	2.98	1.02	2.10	2.27
1864 .....	—17	2.74	2.47	0.77	0.63	3.07	2.17	7.51
1848 .....	—27	4.76	2.04	2.66	1.58	6.74	2.21	6.25
1869 .....	—28	1.53	1.47	1.03	3.34	4.32	3.05	4.42
Average of 12 positive .....		3.70	2.21	1.44	2.22	3.82	5.80	5.62
Average of 11 negative .....		2.43	2.42	1.62	2.05	2.76	4.78	5.56
All (25) .....		3.26	2.58	1.47	1.99	3.54	5.45	5.70

TABLE I.—*Barbados sugar crop and monthly rainfall*—Continued.

Year.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual—	
						Rain.	Crop.
	<i>Inches.</i>	<i>Inches.</i>	<i>Inches.</i>	<i>Inches.</i>	<i>Inches.</i>	<i>Inches.</i>	<i>Hhds.</i>
1868.....	5.62	4.63	8.20	4.42	1.40	44.60	58,250
1866.....	11.89	4.22	8.99	7.85	5.80	59.68	57,188
1852.....	7.36	8.72	6.53	14.15	6.66	58.77	48,611
1871.....	5.37	6.70	6.33	4.03	4.08	41.46	53,907
1854.....	5.11	3.97	7.03	11.19	3.79	50.88	45,181
1867.....	9.62	8.54	12.74	4.30	3.89	69.93	51,304
1858.....	4.24	3.54	10.46	6.13	5.22	45.22	50,788
1856.....	7.80	5.98	6.15	7.25	4.21	48.49	43,077
1861.....	4.65	6.77	7.60	7.50	7.11	73.82	49,745
1862.....	7.23	4.74	11.18	7.40	2.36	59.27	46,120
1865.....	8.91	5.07	11.00	4.53	6.58	63.64	46,068
1855.....	12.84	9.27	5.12	5.98	5.41	77.31	39,290
1851.....	7.00	9.25	6.53	4.29	6.05	59.40	38,731
1853.....	8.08	7.75	10.43	8.36	2.20	68.84	38,719
1860.....	7.93	7.31	13.30	7.97	5.09	57.91	42,684
1863.....	9.34	4.99	2.89	6.45	3.27	42.88	42,281
1850.....	6.82	3.34	10.17	9.61	6.36	67.88	35,302
1859.....	3.21	4.80	10.13	10.18	3.74	54.22	39,666
1870.....	5.61	5.03	11.24	8.37	3.38	60.17	39,270
1857.....	6.33	7.93	6.53	9.74	3.10	60.90	38,798
1849.....	6.82	4.74	8.53	1.42	3.73	52.77	33,077
1847.....	5.26	10.20	7.11	8.45	3.73	48.10	33,703
1864.....	7.37	10.77	9.14	6.31	6.16	59.19	36,199
1848.....	7.53	5.41	11.78	5.79	7.04	63.77	28,169
1869.....	6.95	4.56	6.99	5.13	5.73	48.52	32,150
Average of 12 positive..	7.55	5.59	8.44	7.06	4.71	58.18	-----
Average of 11 negative..	6.66	6.28	8.89	7.22	4.66	55.15	-----
All (25).....	7.24	6.24	8.69	7.06	4.50	57.74	-----

TABLE II.—*Barbados sugar crop and rainfall of the growing period.*

Year.	Total rainfall of cur- rent year.	Crop.	Date of first ship- ment.	Total rainfall during growing sea- son of the crop of current year.			
				All of preced- ing year.	Latter half of year before.	Total.	First half of year be- fore.
	<i>Inches.</i>	<i>Hhds.</i>		<i>Inches.</i>	<i>Inches.</i>	<i>Inches.</i>	<i>Inches.</i>
1847.....	48.10	33,703	Jan. 21	-----	-----	-----	-----
1848.....	63.77	28,169	Feb. 18	48.10	-----	-----	-----
1849.....	52.77	33,077	Jan. 21	63.77	37.02	100.79	11.08
1850.....	67.88	35,302	Jan. 22	52.77	43.80	96.57	19.97
1851.....	59.40	33,731	Jan. 18	67.88	30.88	98.76	21.89
1852.....	58.77	43,611	Jan. 17	59.40	45.31	104.71	22.57
1853.....	68.84	38,719	Feb. 12	58.77	39.75	98.52	19.65
1854.....	50.88	45,181	Jan. 19	68.84	40.81	109.65	17.96
1855.....	77.31	39,290	Feb. 17	50.88	40.71	91.59	28.13
1856.....	48.49	43,077	Jan. 23	77.31	36.77	114.08	14.11
1857.....	60.90	38,798	Feb. 14	48.49	46.62	95.11	30.69
1858.....	45.22	50,788	Feb. 10	60.90	34.25	95.15	14.24
1859.....	54.22	39,666	Mar. 7	45.22	40.82	86.04	20.08
1860.....	57.91	42,684	Feb. 6	54.22	33.28	87.50	11.94
1861.....	73.82	49,745	Feb. 17	57.91	37.78	95.69	16.44
1862.....	59.27	46,120	-----	73.82	45.50	118.32	12.41
1863.....	42.38	42,281	Feb. 14	59.27	41.91	101.18	31.91
1864.....	59.19	36,199	Mar. 9	42.38	38.30	80.68	20.97
1865.....	68.64	46,068	Mar. 6	59.19	30.59	89.78	11.79
1866.....	59.68	57,188	Feb. 7	68.64	47.26	115.90	11.93
1867.....	69.93	51,304	Feb. 22	59.68	43.44	104.12	25.20
1868.....	44.60	58,250	Feb. 8	69.93	44.98	114.91	14.70
1869.....	48.52	32,150	Mar. 1	44.60	46.59	91.19	23.34
1870.....	60.17	39,270	Feb. 22	48.52	30.53	79.05	14.07
1871.....	41.46	53,907	Feb. 21	60.17	33.78	93.95	14.74
1872.....	48.36	39,167	Mar. 4	41.46	39.25	80.71	20.92
1873.....	-----	-----	-----	48.36	30.16	78.55	11.30

TABLE III.—*Barbados sugar crop and rainfall of preceding year.*

Year.	Rainfall.	Above (+) or below (-) the average of crop of fol- lowing year.	Year.	Rainfall.	Above (+) or below (-) the average of crop of fol- lowing year.
	<i>Inches.</i>	<i>Per cent.</i>		<i>Inches.</i>	<i>Per cent.</i>
1855.....	77.81	+11	1864.....	59.19	+ 2
1861.....	73.82	+ 2	1852.....	58.77	0
1867.....	69.93	+29	1860.....	57.91	+10
1853.....	68.84	+17	1859.....	54.22	- 5
1865.....	68.64	+27	1849.....	52.77	- 9
1850.....	67.88	0	1854.....	50.88	+ 1
1848.....	63.77	-15	1869.....	48.52	-13
1857.....	60.90	+13	1856.....	48.49	-14
1870.....	60.17	+20	1847.....	48.10	-27
1866.....	59.68	+14	1858.....	45.72	-12
1851.....	59.40	+25	1868.....	44.60	-23
1862.....	59.27	+ 6	1863.....	42.88	-19

NOTE.—In calculating the average crop and the respective annual excesses or deficits given in Tables I and III Governor Rawson says that “ he has made an arbitrary division of the whole period into two sections marked by the introduction of the use of guano as a fertilizer.” For the first section, 1847–1856, inclusive, he considers 38,795 hogsheads as the average, but for the second section, 1857–1872, inclusive, he takes 45,036 hogsheads as the average. He states that this is virtually assuming that during the whole period climatic and other conditions were nearly constant and that the principal difference was in the introduction of the use of guano and the great increase of crops was due to that. During the first interval an inch of rain corresponded to 642 hogsheads of sugar in the crop of the next year, but during the second interval it corresponded to 800 hogsheads.

## PART III.—STATISTICAL FARM WORK.

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### Chapter XIII.

#### THE CROPS AND CLIMATES OF THE UNITED STATES.

The ultimate object of our inquiry is to determine the exact percentage of the effect of normal and abnormal climates upon special crops in special regions of this country and the relation to the whole crop of the United States. To this end we must first ascertain the climatic effect on the yield per acre, and this is our present special problem, leaving it to the statistician and census taker to ascertain how many acres are under cultivation and what the actual effect will be in bushels or pounds. The climatologist, or Weather Bureau, has only to determine numerically the climatic effect upon a given unit area.

The tables of yield per acre for ten important crops and for all years will be given in a subsequent portion of this section, but the study of these must be preceded by several studies into matters that are not strictly climatic, but which nevertheless enter into the statistics of actual harvests and obscure the strictly climatic influences. Thus the statistics must be corrected in some way for the effect of the customary modes of cultivation and the quantity of seed that is sown, on which point I give statistics appropriate to the United States.

Again, before comparing our climatic data with the phenomena of vegetation we must know something of the average date of seeding, with respect to which I have given the dates for seeding of winter wheat.

The corresponding dates for rye will not differ very much. The dates for maize, potatoes, tobacco, and cotton have already been given for special localities, but still require to be tabulated in a general way. The necessary climatic data are given in my next section for twenty Signal Service stations, and I regret that the shortness of time has not allowed me to give more complete data for these and for all other stations, but the tables here presented will serve to show the form in which such data should be presented for the greatest convenience in phenological studies.

But before entering upon so extensive a system of numerical comparisons it is necessary to bear in mind certain principles which I would illustrate in the following remarks.

### **VARIABILITY OF RESULTS FROM PLAT EXPERIMENTS.**

The reliability of the data obtained from experiments on small plats of ground, and on which we should naturally place much reliance in discussing the relation between climates and crops, is a matter of the first importance, and we must begin our study with an attempt to obtain a clear idea as to the extent to which such data are fit to be used as a basis for our studies. In the light of all that has thus far been ascertained with reference to the nature of the influences at work to increase or diminish the resulting crop, we may safely say that the results obtained from two different plats will not be comparable with each other and still less be applicable to the larger fields harvested by the farmers, unless we know for each plat or field the absolute or relative conditions as to the following matters:

(1) The mechanical condition of the soil as affecting aeration, percolation, and temperature.

(2) The chemical nature of the original soil.

(3) The character, proportion, and uniformity of distribution of the fertilizers and the history of the previous rotations of crops on these plats; the influence of climate, rain, and drainage on the available nutrition in the soil.

(4) The dates of cultivation and application of the fertilizers.

(5) The exact area of the plats.

(6) The distance apart of the hills or stalks.

(7) The number and quality of seeds sown per acre.

(8) The moisture in the soil at the beginning and the quantity and times of rain or irrigation.

(9) The chemical and biological quality of the rain or irrigation water—i. e., rain or snow water; rain with much or little nitrogenous compounds and biological germs.

(10) The injury by insects and animals.

(11) The temperature of the soil.

(12) The remaining climatic details as to heat, sunshine, dryness, and velocity of the wind.

(13) The sterility of the soil as to the microbic life that seems indispensable to the success of certain crops or to the growth of the plants.

(14) The nature of the climate in which the seed and its immediate ancestor was grown.

In the total absence of knowledge as to many of these points and fragmentary knowledge on others, a simple direct comparison between the results of two plats lying side by side and that have in some few respects been treated alike must be entirely misleading. But the extent to which such comparisons are deceptive, or rather the



extent to which we can rely upon them for further instruction, can only be estimated by a study of such exact experiments as have been made at the experiment stations throughout this country and Europe. Some illustrations of this matter are given by C. S. Plumb, under the title of the "Fallacies of plat experimentation" (Agr. Sci., Vol. II, p. 4), to which I will add the following remarks. Two sets of measures are taken from the results of the year 1887 at Geneva, N. Y. The plats were arranged in two series, or two fields, but were in every respect as much alike as possible and supposed to be identical. The harvests from the respective plats were as follows:

Plat.	Weight of good ears.		Plat.	Weight of good ears.	
	Series C.	Series E.		Series C.	Series E.
	<i>Pounds.</i>	<i>Pounds.</i>		<i>Pounds.</i>	<i>Pounds.</i>
1.....	237.2	223.8	14.....	172.8	177.5
2.....	224.2	216.9	15.....	171.8	167.1
3.....	222.7	199.0	16.....	172.6	182.2
4.....	242.0	222.2	17.....	183.4	150.1
5.....	264.2	196.1	18.....		140.2
6.....	232.9	174.2	19.....		128.2
7.....	155.3	182.7			
8.....	107.8	213.6	Average.....	204.6	182.7
9.....	222.2	197.6			
10.....	243.8	186.0	Yield per acre..... bushels..	51.1	45.7
11.....	224.6	168.1	Number of plants.....	12,380	12,820
12.....	209.0	169.1	Number of good ears.....	12,180	11,400
13.....	191.7	177.6			

The individual differences between these 36 plats simply show that the conditions were not so uniform as the author supposed; in fact, the regular gradations from the high numbers at the top of the column to the low ones at the bottom show that there was a slight systematic difference among the plats in each series. On the other hand, the decided apparent differences between the two series, as well as between the plats, is very largely of the nature of those differences that are called accidental in the theory of exact measurements. Similar differences in a long series of observations of the temperature or the rainfall of any locality are spoken of not as accidental error but as the variability of the climate, and these differences in the present case may properly be treated as variability in the productive power of any plat compared with the neighboring plat without for the moment inquiring as to the cause of this variability. But the mathematical theory of probabilities, or chance, or errors of observation, is equally applicable to this question of variability due to unknown influences. According to that theory we obtain the index of variability if we take the difference between the average of a series and the individual num-

bers in the series and treat these departures according to the following formula:

Index of variability of the plats equals

$$\pm 0.864 \sqrt{\frac{\text{Sum of all the (Departures)}^2}{\text{Number of departures less 1}}}$$

which formula may be interpreted as meaning that from the squares of the departures added together and divided by the number of plats less 1 we derive an index called the "probable uncertainty of 1 measure," or "the probable variability of 1 plat as compared with all the plats of the series." Again, knowing this uncertainty of any one measure, we find the "probable uncertainty of the average of  $n$  measures" by the following formula:

$$\text{Probable uncertainty of the average} = \pm \frac{\text{Index}}{\sqrt{n}}.$$

This latter formula is to be interpreted as meaning that there is an even chance that the computed average is too large or too small by this probable uncertainty. Applying these principles to the measures of plats C and E, I obtain the figures 34.3 and 22.9 as the indices of variability and 8.33 and 5.26 as the probable errors of the two averages. That is to say, so far as any internal evidence is given by the discrepancies between the measurements of the plats themselves, there is an even chance that the crop from a plat in series C is between the limits 212.9 and 196.3 or outside of these limits; similarly, for series E there is an even chance that the crop from any plat is within the limits 188.9 and 177.4 or outside of these limits. But the numbers within each of these two series overlap each other so much that it is perfectly possible that if we could increase the number of plats in each series sufficiently, all other conditions remaining the same, we should eventually arrive at very nearly the same average value for each. In other words, the mere difference of the two averages 204.6 and 182.7 is no evidence that in this particular case there was any important constant difference between the plats of series C and those of series E, but that, on the contrary, unknown sources of influence are at work in each series and in all the plats that are more important than any that were thought of when the experimenter endeavored to make these 36 plats perfect duplicates of each other.

Professor Plumb shows that this difference did not depend upon the previous crops or treatment of the plats during the previous five years. It certainly did not depend on the meteorological climate, the mechanical condition of the soil, nor on the seeds, nor on injury by insects and animals. We may possibly find a partial explanation in the irregular distribution of microbic life in the soil, but it is more likely that it depended upon the inherent variability of the

vitality of the seed, due to unknown causes, and which we have no means of measuring except by just such experiments as these. The elaborate measurements made by Lawes and Gilbert at Rothamsted, England, since 1850, furnish innumerable illustrations of this same principle; so, also, do those of W. R. Lazenby, at Columbus, Ohio, and many others.

We shall therefore hope to derive more reliable results from the study of farming operations on a large scale, taking the averages by counties and States where the crops have been carefully measured. We may possibly eliminate irregularities in many disturbing elements, and be able to clearly set forth that small percentage by which the crops of the United States as a whole are influenced by purely climatic conditions. Such influences may in extreme cases be very large, but, on the average, they are not so large as those which depend upon seed, cultivation, rotation, and fertilizers.

#### **EFFECT OF VARIATIONS IN METHOD OF CULTIVATION AND IN QUALITY OF SEED FOR DIFFERENT REGIONS AND YEARS.**

Among the modes of cultivation that materially affect the development of the plant and the quantity of the harvest must be considered the practice of sowing seed broadcast with the hand as contrasted with that of putting it in with the drilling machine. The drilling requires less seed, the saving being about one-half bushel per acre; the grain is buried more evenly, starts more uniformly, and stands the droughts better. Moreover, the drilled wheat fields are considered to yield more per acre, although it is difficult to state how much is due to the drilling independent of the character of the soil, because in general the fields that are drilled are most apt to be those free from stumps, stones, and steep slopes, while the broadcast sowing is especially adapted to this latter character of field. The census of 1879 shows that the drilled fields of winter wheat in Ohio yielded 50 per cent more than the broadcast fields of summer wheat in the Northwest; but it is not plain what proportion of this is respectively due to the drilling and to the soil.

In the report for 1875 of the Department of Agriculture (p. 42) the following statistics are given as to the percentage of area drilled, the quantity of seed per acre, and the increase of harvest in drilled fields over that in broadcasted fields:

The following table omits the New England States, which produce little wheat, nearly all of which is sown broadcast. The wheat area of New York is divided equally between the two methods. In New Jersey, Pennsylvania, Delaware, and Maryland the drill greatly predominates. In the Southern States the area is small, particularly in the cotton States, and the drill is comparatively unknown. North of the Ohio River, in the winter-wheat States, the drill is very

generally used, the proportion rising to 76 per cent in Illinois. In the spring-wheat region there are several reasons for prominence of broadcasting. One comes from a prevalent practice of sowing wheat on the irregular surface of a cornfield without plowing; another is found in the use of the combined cultivator and broadcast seeder, which destroys many of the weeds that would otherwise be left between the drills. \* \* \* The result of the investigation shows that 47 per cent of the winter wheat and 30 of the spring, or 37 of both, represent the proportion seeded by the drill. The improvement by drilling is made to average 10 per cent. The average quantity of seed used for seeding winter wheat is 1.35 bushels per acre; 1.24 for drilled, 1.44 for the sown. The details are as follows:

*Percentages for 1875.*

State.	Relative area—		Increase of product by drilling.	Seed per acre.	
	Sown.	Drilled.		Broad-casting.	Drilling.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Bushels.</i>	<i>Bushels.</i>
New York .....	50	50	13	1.80	1.60
New Jersey .....	45	55	6	1.95	1.60
Pennsylvania .....	30	70	12	1.74	1.49
Delaware .....	28	74	10	1.75	1.50
Maryland .....	24	76	7	1.70	1.43
Virginia .....	62	38	12	1.44	1.21
North Carolina .....	97	3	-----	1.07	0.83
South Carolina .....	99	1	-----	1.00	0.70
Georgia .....	99	1	-----	1.00	0.90
Alabama .....	99	1	-----	1.00	-----
Mississippi .....	99	1	-----	1.25	-----
Texas .....	98	2	-----	1.18	0.90
Arkansas .....	100	0	-----	1.10	-----
Tennessee .....	96	4	10	1.20	1.10
West Virginia .....	58	42	12	1.53	1.33
Kentucky .....	92	8	10	1.86	1.11
Ohio .....	89	61	16	1.57	1.33
Michigan .....	49	51	9	1.62	1.40
Illinois .....	24	76	19	1.52	1.24
Indiana .....	49	51	15	1.48	1.21
Missouri .....	62	38	21	1.52	1.21
Kansas .....	55	45	16	1.49	1.23
Nebraska .....	51	49	17	1.56	1.25
California .....	98	2	-----	1.33	-----
Oregon .....	81	19	5	1.50	1.21

The following table, from the Agricultural Report for 1882 (p. 636), gives the proportion of winter wheat that was drilled and broadcasted in the autumn and winter of 1881 and 1882 for each State:

State.	Drilled.	Broad-casted.	State.	Drilled.	Broad-casted.
	<i>Per cent.</i>	<i>Per cent.</i>		<i>Per cent.</i>	<i>Per cent.</i>
Connecticut .....	5	95	Louisiana .....	1	99
New York .....	52	48	Texas .....	11	89
New Jersey .....	56	44	Arkansas .....	2	98
Pennsylvania .....	70	30	Tennessee .....	15	85
Delaware .....	75	25	West Virginia .....	40	60
Maryland .....	63	37	Kentucky .....	81	69
Virginia .....	80	70	Ohio .....	78	22
North Carolina .....	8	92	Michigan .....	52	48
South Carolina .....	1	99	Indiana .....	81	19
Georgia .....	2	98	Illinois .....	71	29
Alabama .....	6	94	Missouri .....	58	42
Mississippi .....	1	99	Kansas .....	73	27

As it has not been practicable to obtain data that will accurately present the effect on the crop of the diverse features of cultivation that are independent of climate, I give, in addition to the preceding, the following general statements bearing on the annual crop statistics kindly communicated by Mr. J. R. Dodge, Statistician to the Department of Agriculture. Relative to the seeding and the stand of the crop and other matters, he says:

The practice varies with the kinds of corn. The small northern corn is planted closer than the larger more southern varieties. In the South corn is given greater distances than in the West. It grows larger there and makes more stalk growth and fewer ears. Only one or two stalks are planted in the hill there, while two or three in the middle, and three and even four in the extreme northern latitudes, are sometimes left in the hill. We have allowed one-third of a bushel per acre.

The individual differences in yield per acre in the States of highest, as well as of the lowest yield, are far greater than the differences in these State averages, as produced by differences in soil, in the effects of the various vicissitudes on different soils, in fertility or lack of it, in thoroughness of cultivation.

In the extreme West, beyond the Mississippi, where land is plenty and labor scarce, the cultivation is reduced to the minimum. Satisfactory results are now produced in southern Iowa in winter-wheat growing by simply "cultivating" between corn rows and sowing wheat at a labor expense of 60 cents per acre. The rough surface is favorable for exemption from winter killing, and some records of experiment show an increase of 25 per cent in yield over planting after clover on a smooth surface. This is so notwithstanding the clover soil might be expected to have something like as great an advantage in real fertility over the soil that had grown a crop of maize. The corn exhausts, the clover enriches, and still the yield is

the greater after the corn, because the plants are not much injured by frost.

### EFFECT OF VARIATIONS IN DATES OF SEEDING AND HARVESTING.

The injurious effects of late frosts on early vegetables and on grains sown in the spring is generally annulled in part by a second sowing, so that the crop reports for the year do not show the full extent of the injury done to the plant by the climate.

In a general comparison between the climate and the crops accuracy would require that we know the date of last planting, but in the absence of this fundamental datum we are obliged to use the average dates between which the planting is done in any given State, and such dates are given in the following table and are assumed to refer to the dates of planting the seed which actually brought forth the subsequent harvest, whose yield per acre is given in the tables published by the statistician of the Department of Agriculture.

These tables are also necessary in order to compute the thermal constants and to anticipate the dates of bloom and harvest. The following tables, for 1882 and 1889, as published in the Annual Reports of the Department of Agriculture (pp. 409 and 636, respectively), give the dates of seeding for wheat:

State.	1882.			1889.		
	Date of seeding.		Average date of seeding.	Date of seeding.		Average date of seeding.
	From—	To—		From—	To—	
Connecticut.....	Sept. 1	Nov. 1	Sept. 25	Sept. 1	Oct. 25	Sept. 25
New York.....	Aug. 15	Oct. 30	Sept. 16	Aug. 15	Oct. 15	Sept. 15
New Jersey.....	Aug. 23	Nov. 10	Sept. 23	Aug. 25	Oct. 25	Sept. 25
Pennsylvania.....	Aug. 20	Oct. 20	Sept. 20	Aug. 10	Oct. 30	Sept. 19
Delaware.....	Sept. 20	Oct. 10	Oct. 1	Sept. 15	Nov. 1	Oct. 10
Maryland.....	Sept. 1	Dec. 1	Oct. 13	Aug. 20	Nov. 20	Oct. 13
Virginia.....	Aug. 20	Nov. 25	Oct. 15	Sept. 5	Dec. 1	Oct. 19
North Carolina.....	Sept. 1	Jan. 10	Oct. 29	Sept. 1	Dec. 15	Nov. 5
South Carolina.....	Oct. 1	Jan. 1	Nov. 1	Oct. 1	Dec. 10	Nov. 13
Georgia.....	Sept. 1	Jan. 10	Nov. 2	Sept. 1	Dec. 25	Nov. 14
Alabama.....	do	Dec. 20	Nov. 3	Sept. 15	Jan. 1	Nov. 7
Mississippi.....	do	Dec. 1	do	do	Dec. 30	Nov. 5
Louisiana.....	do	Nov. 20	Nov. 5	do	do	do
Texas.....	do	Mar. 15	Nov. 7	Sept. 1	Feb. 1	Nov. 6
Arkansas.....	do	Jan. 15	Oct. 23	do	Jan. 10	Nov. 1
Tennessee.....	Aug. 1	Dec. 15	Oct. 15	do	Dec. 20	Oct. 23
West Virginia.....	Aug. 20	Nov. 15	Sept. 30	do	Nov. 15	Oct. 2
Kentucky.....	Aug. 25	Dec. 20	Oct. 7	do	Dec. 10	Oct. 12
Ohio.....	Aug. 1	Nov. 20	Sept. 20	Aug. 25	Nov. 15	Sept. 24
Michigan.....	Aug. 20	Nov. 15	Sept. 17	Aug. 20	Nov. 1	Sept. 15
Indiana.....	Aug. 15	do	Sept. 19	do	Nov. 20	Sept. 24
Illinois.....	Aug. 20	Nov. 10	Sept. 20	Aug. 25	Nov. 13	Sept. 23
Missouri.....	Aug. 15	Dec. 1	Sept. 25	Aug. 15	Dec. 1	Sept. 20
Kansas.....	Aug. 1	Jan. 1	Sept. 23	do	do	Sept. 24
California.....				Sept. 1	May 1	Dec. 27
Oregon.....				Sept. 15	Apr. 1	Nov. 25

The following table gives dates of sowing and ripening, especially in America additional to those given by Lippincott (1863), and in many cases will give useful indications of the progressive change that has gone on since 1860 in methods of cultivation and in the habits of the wheat itself:

Locality.	Latitude north.	Date of sowing.	Date of reaping.	Duration.	Variety of wheat and remarks.
	° /			<i>Days.</i>	
Delta of Egypt .....		Nov. — .....	May — .....	180	
Europe.					
Malta .....		Dec. 1 .....	May 13 .....	163	
Palermo, Sicily .....		do .....	May 20 .....	170	
Naples .....		Nov. 16 .....	June 2 .....	195	
Rome .....		Nov. 1 .....	July 2 .....	242	
Alps:					
3,000 feet .....		Sept. 12 .....	Aug. 7 .....	329	
4,000 feet .....		Sept. 8 .....	Aug. 14 .....	340	
Central Germany .....		Nov. 1 .....	July 16 .....	187	
South of England .....			Aug. 4 .....		
Middle of Sweden .....			do .....		
United States.					
Aroostook County, Me.	46 47	May 15 .....	Sept. 1 .....		
Franklin County, Me.	45 00	May 20 .....	Sept. 20 .....		
Penobscot County, Me.	45 00	May 21 to June 1 ..	Aug. 15 .....		
Somerset County, Me.	45 00	May 25 to June 1 ..	Aug. 20 to Sept. 20 ..		
Washington County, Me.	45 00	Apr. 10 to May 10 ..	Sept. 10-20 .....		
St. Lawrence County, N. Y.	44 40	Apr. to June .....	August .....		
Do .....	44 40	Sept. to Nov .....	July .....		
Windsor County, Vt.	43 30	Sept. 18 .....	July 25 .....		
Oshkosh County, Wis.	44 00	Sept. 1 .....	Aug. 15 .....		
Walworth County, Wis.	43 00	Sept. 1-15 .....	July 20 .....		
Hillsdale County, Mich.	42 00	Sept. 10-25 .....	July 10-20 .....		
Wayne County, Mich.	42 15	Sept. 5-25 .....	July 5-15 .....		
Washtenaw County, Mich.	42 15	Sept. 1-20 .....	July 8-20 .....		
Genesee County, N. Y.	43 00	Aug. 15 to Sept. 15 ..	July 25 .....		
Livingston County, N. Y.	42 45	Sept. 15 .....	July 20 to Aug. 20 ..		
Ontario County, N. Y.	42 45	Aug. 20 to Sept. 25 ..	July 15 to Aug. 1 ..		
Monroe County, N. Y.	43 00	Sept. 25 .....	July 8 .....		May.
Seneca County, N. Y.	42 45	Sept. 10-20 .....	July 20 .....		
Do .....	42 45	Sept. 2 .....	July 13 .....		Dayton.
Ulster County, N. Y.	41 45	Sept. 1-20 .....	July 10-20 .....		Mediterranean.
Steuben County, N. Y.	42 15	Aug. 25 to Sept. 10 ..	July 25 .....		
Hampshire County, Mass.	42 00	Sept. 5 .....	do .....		



Locality.	Latitude north.	Date of sowing.	Date of reaping.	Duration.	Variety of wheat and remarks.
	° /			Days.	
Madison County, Iowa.	42 00	September.....	July 6-18 .....		Spring.
Scott County, Iowa.	42 00	April.....	July.....		
Henry County, Iowa.	41 00	September.....	July 1 .....		
Marion County, Iowa.	41 00	Apr. 1-20 .....	July 15 .....		Do.
Do .....	41 00	Aug. 15 to Sept. 20..	July 4 .....		
Lee County, Iowa.	40 45	September.....	July 5-12 .....		
Menard County, Ill.	40 00	Oct. 1-15.....	June 28 to July 10..		
St. Clair County, Ill.	38 30	Sept. 28 to Oct. 18 ..	.....		
Howard County, Mo.	39 00	Sept. 1 to Oct. 30 ...	June 30.....		
Delaware County, Ind.	40 15	Sept. 15.....	July 1-15 .....		
Rush County, Ind.	39 30	September.....	June 25 to July 5...		
Wayne County, Ind.	39 45	Sept. 1 to Oct. 15 ...	June 25 to July 7...		
Harrison County, Ohio.	40 15	Sept. 1-20.....	July 1-10 .....		Soule.
Athens County, Ohio.	39 30	Sept. 8.....	July 1 .....		Rock.
Clinton County, Ohio.	39 20	.....	July 4 .....		
Lawrence County, Ohio.	38 40	October.....	May 30 .....		
Mahoning County, Ohio.	41 00	.....	July 15 .....		Mediterranean.
Fairfield County, Ohio.	39 45	.....	June 15 to July 1...		Do.
Westmoreland County, Pa.	40 30	Sept. 10 to Oct. 15 ..	July 8 .....		Do.
Fayette County, Pa.	40 00	Sept. 1-20.....	July 7 .....		
Mifflin County, Pa.	40 30	Sept. 10 to Oct. 1 ...	July 1 .....		
Dauphin County, Pa.	40 30	Sept. 1 to Oct. 1 ....	July 4-15 .....		Blue Stem.
Berks County, Pa.	40 30	Sept. 10-15.....	July 4-20 .....		
Philadelphia County, Pa.	40 00	Sept. 15 to Oct. 15 ..	July 15 .....		
Bergen County, N.J.	41 00	Oct. 1.....	July 5-15 .....		Do.
Gloucester County, N.J.	39 45	.....do .....	July 1-10 .....		
Salem County, N.J.	39 30	Sept. 30 to Oct. 7 ...	June 25 to July 1...		
Newcastle County, Del.	39 00	Sept. 20 to Oct. 10 ..	.....		Do.
Dover County, Del.	39 00	.....do .....	June 15-23.....		
Sussex County, Del.	38 50	Sept. 28 to Oct. 15 ..	June 25 to July 1...		
Harford County, Md.	39 45	Sept. 1 until frost..	June 25 to July 15..		
Jefferson County, Va.	39 15	Sept. 25 to Oct. 15 ..	June 25 to July 1...		Do.
Do .....	39 15	Sept. 4-23.....	July 22 .....		
Richmond County, Va.	37 50	Sept. 16, 1859.....	June 14, 1860.....		
Do.....	37 50	.....	June 2.....		Early Conner.
Do.....	37 50	.....	May 26, 1842 .....		May.

Locality.	Latitude north.	Date of sowing.	Date of reaping.	Duration.	Variety of wheat and remarks.
	° ' "			<i>Days.</i>	
Franklin County, Va.	37 00	Oct. 1 to Dec. 15 .....	June 20 to July 10 .....	.....	Early May.
Buckingham County, Va.	37 40	Oct. 1 to Nov. 15 .....	June 15 to July 4 .....	.....	
Mason County, Ky.	38 30	Sept. 1 to Oct. 15 .....	June 2 .....	.....	
Clark County, Ky.	38 00	Sept. 15 to Oct. 30 .....	June and July .....	.....	
Logan County, Ky.	37 00	October and November .....	June 10-30 .....	.....	
Cabarras County, N. C.	35 30	November .....	June 1-10 .....	.....	Do.
Bedford County, Tenn.	35 30	Sept. 15 to Nov. 15 .....	June 1-14 .....	.....	
Habersham County, Ga.	34 45	Sept. 15 to Dec. 1 .....	June 15 to July 15 .....	.....	
Cherokee County, Ala.	34 15	Oct. 1 to December .....	June 1-15 .....	.....	
Montgomery County, Ala.	32 30	.....	May 31 .....	.....	
Gaudalupe County, Tex.	30 00	Jan. 1 .....	June 1 .....	.....	
Santa Fe, N. Mex.	35 40	April .....	August .....	.....	
Albuquerque, N. Mex.	35 10	February and March .....	July 31 .....	.....	
Donna Ana County, N. Mex.	32 30	Jan. 15 .....	August .....	.....	
Utah Territory .....	43 00	Sept. 1 to May 1 .....	June to September .....	.....	
Stanislaus County, Cal.	.....	November .....	June 1 .....	.....	White Chili.
<i>British North America.</i>					
Fort Fraser .....	54 30	.....	.....	.....	West of the Rocky Mountains.
Cumberland House, on Saskatchewan River.	53 57	.....	.....	.....	Sown May 8; reaped in August.
Red River settlement.	50 00	.....	.....	.....	Wheat grows luxuriantly.
Fort Francis, Rainy Lake district.	48 33	.....	.....	.....	Sown May 1; reaped in August (120 days).
Quebec, Canada ..	46 49	.....	.....	.....	Wheat succeeds.
Prince Edward Island.	46 12	.....	.....	.....	Extensively grown.
Fredericton, New Brunswick.	46 00	.....	.....	.....	Wheat succeeds.
Pictou, Nova Scotia.	45 34	.....	.....	.....	August mean, 63; wheat succeeds.
<i>Beyond north polar limit of successful wheat culture.</i>					
Sitka, Alaska .....	57 00	.....	.....	.....	Wheat does not ripen.
Fort York, on Hudson Bay.	57 00	.....	.....	.....	Do.
Edmonton, on Saskatchewan River.	53 40	.....	.....	.....	Often destroyed by frost.
Carlton House, on Saskatchewan River.	52 51	.....	.....	.....	Do.
Fort Liard, McKenzie River.	60 00	.....	.....	.....	Grows occasionally.
St. Johns, Newfoundland.	47 33	.....	.....	.....	Wheat does not ripen.

Locality.	Latitude north.	Date of sowing.	Date of reaping.	Duration.	Variety of wheat and remarks.
	° /			<i>Days.</i>	
Madison County, Iowa.	42 00	September.....	July 6-18 .....		Spring.
Scott County, Iowa.	42 00	April.....	July .....		
Henry County, Iowa.	41 00	September.....	July 1 .....		
Marion County, Iowa.	41 00	Apr. 1-20 .....	July 15 .....		Do
Do .....	41 00	Aug. 15 to Sept. 20..	July 4 .....		
Lee County, Iowa.	40 45	September.....	July 5-12 .....		
Menard County, Ill.	40 00	Oct. 1-15.....	June 28 to July 10..		
St. Clair County, Ill.	38 30	Sept. 28 to Oct. 18 ..	.....		
Howard County, Mo.	39 00	Sept. 1 to Oct. 30 ...	June 30.....		
Delaware County, Ind.	40 15	Sept. 15.....	July 1-15 .....		
Rush County, Ind.	39 30	September.....	June 25 to July 5...		
Wayne County, Ind.	39 45	Sept. 1 to Oct. 15 ...	June 25 to July 7...		
Harrison County, Ohio.	40 15	Sept. 1-20.....	July 1-10 .....		Souls.
Athens County, Ohio.	39 30	Sept. 3.....	July 1 .....		Rock.
Clinton County, Ohio.	39 20	.....	July 4 .....		
Lawrence County, Ohio.	38 40	October.....	May 30 .....		
Mahoning County, Ohio.	41 00	.....	July 15 .....		Mediterranean.
Fairfield County, Ohio.	39 45	.....	June 15 to July 1...		Do.
Westmoreland County, Pa.	40 30	Sept. 10 to Oct. 15 ..	July 8 .....		Do.
Fayette County, Pa.	40 00	Sept. 1-20.....	July 7 .....		
Mifflin County, Pa.	40 30	Sept. 10 to Oct. 1 ...	July 1 .....		
Dauphin County, Pa.	40 30	Sept. 1 to Oct. 1 ....	July 4-15 .....		Blue Stem.
Berks County, Pa.	40 30	Sept. 10-15.....	July 4-20 .....		
Philadelphia County, Pa.	40 00	Sept. 15 to Oct. 15 ..	July 15 .....		
Bergen County, N.J.	41 00	Oct. 1 .....	July 5-15 .....		Do.
Gloucester County, N.J.	39 45	.....do .....	July 1-10 .....		
Salem County, N.J.	39 30	Sept. 30 to Oct. 7 ...	June 25 to July 1...		
Newcastle County, Del.	39 00	Sept. 20 to Oct. 10 ..	.....		Do.
Dover County, Del.	39 00	.....do .....	June 15-23.....		
Sussex County, Del.	38 50	Sept. 28 to Oct. 15 ..	June 25 to July 1...		
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Jefferson County, Va.	39 15	Sept. 25 to Oct. 15 ..	June 25 to July 1...		Do.
Do .....	39 15	Sept. 4-23.....	July 22 .....		
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Do.....	37 50	.....	May 26, 1842 .....		May.

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	° ' "			Days.	
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Clark County, Ky.	38 00	Sept. 15 to Oct. 30 ..	June and July .....	.....	
Logan County, Ky	37 00	October and November.	June 10-30.....	.....	
Cabarras County, N. C.	35 30	November .....	June 1-10.....	.....	Do.
Bedford County, Tenn.	36 30	Sept. 15 to Nov. 15..	June 1-14.....	.....	
Habersham County, Ga.	34 45	Sept. 15 to Dec. 1...	June 15 to July 15..	.....	
Cherokee County, Ala.	34 15	Oct. 1 to December.	June 1-15.....	.....	
Montgomery County, Ala.	32 30	.....	May 31 .....	.....	
Gaudalupe County, Tex.	30 00	Jan. 1.....	June 1.....	.....	
Santa Fe, N. Mex.	35 40	April.....	August.....	.....	
Albuquerque, N. Mex.	35 10	February and March.	July 31 .....	.....	
Donna Ana County, N. Mex.	32 30	Jan. 15.....	August.....	.....	
Utah Territory...	43 00	Sept. 1 to May 1....	June to September	.....	
Stanislaus County, Cal.	.....	November .....	June 1.....	.....	White Chili.
<i>British North America.</i>					
Fort Fraser.....	54 30	.....	.....	.....	West of the Rocky Mountains.
Cumberland House, on Saskatchewan River.	53 57	.....	.....	.....	Sown May 8; reaped in August.
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<i>Beyond north polar limit of successful wheat culture.</i>					
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Edmonton, on Saskatchewan River.	53 40	.....	.....	.....	Often destroyed by frost.
Carlton House, on Saskatchewan River.	52 51	.....	.....	.....	Do.
Fort Liard, McKenzie River.	60 00	.....	.....	.....	Grows occasionally.
St. Johns, Newfoundland.	47 33	.....	.....	.....	Wheat does not ripen.

**BRIEF SUMMARY OF CONCLUSIONS.**

Some of the principal points that have been brought out in this collection of data will seem like the expression of ideas that have long been known, yet whose importance has probably been underrated by those who desired to deduce definite numerical relations between the climate and the crops of any locality.

(1) We have seen that in a general way the plant, like every other living being, adapts itself, when possible, to its climatic surroundings, and therefore will produce some crop, if possible, the first year and will do better and better in the next few succeeding years if the seasons are not too severe.

So sensitive is the plant to a change of environment that the ordinary seasonal irregularities from year to year have a strong influence upon it, so that the general disposition acquired by the seed in a single dry or wet, or cold, or early, or late season prepares it for a corresponding dry or wet, cold, early, or late season next year. Or, again, a "sport" that has unexpectedly developed under the special influence of a given season and soil, and has acquired to a high degree characteristics which make it harmonize with that season, becomes the progenitor of some important variety whose adoption may, in a few years, revolutionize the agriculture of that region. The weather of any growing season affects the crops of future years by modifying the seeds of the current crop. The current season and the resulting seeds must harmonize together.

(2) If, instead of adapting the plant to the climate, we, for instance, plant the seeds proper for a moist climate in an arid region, and if we must therefore artificially irrigate in order to secure a crop, such irrigation should be looked upon, not as establishing an expensive custom to be adhered to in future ages, but as simply a temporary device to be managed in the interests of the evolution of new varieties that can eventually be cultivated in that soil and climate without irrigation. This is the result that nature has herself frequently achieved by the slow process of carrying seeds, step by step, from moist to arid regions, and which man endeavors to hasten when he carries seeds by railroad and steamship from England to our arid region.

(3) Inasmuch as the cultivation of the cereals cotton, tobacco, sugar, and other important crops will hardly be attempted except in regions where the climate is known to be reasonably in harmony with the seed that is planted, therefore we may assume that an average crop is certain under the average climatic conditions. The departure of any special season as to climate will produce a corresponding departure as to crop, but the latter must be expressed as a percentage of the average ordinary crop, and not simply in absolute measure,

as bushels or pounds, since the absolute crop depends so much upon the soil, the manuring, the cultivation, the thickness of seeding, and other details. On the other hand, the crop of one season must have some relation to the crop of the preceding season by reason of the inherited tendencies of the seed from which it was raised. The climatic factors  $\frac{\text{rainfall or useful moisture}}{\text{temperature or heat}}$  and  $\frac{\text{rainfall or nutriment}}{\text{sunshine}}$  are, as shown by Linsser, the data that must be compared with the resulting harvests.

(4) It is evident that the question of the effect of climate on a given crop in the past is not so important as the prediction of what crop will be harvested from a given field already planted. On this point I have given all the illustrations that I could find, especially in Chapter XII, showing how from an analysis of a sample at any given date one should be able to predict the resulting crop. The result can be made correct to within 10 per cent, if we allow for the ordinary average irregularities of the climate, a statement of whose extent can easily be made up from meteorological records. As to extraordinary irregularities of climate which can not be foreseen, I remark:

(a) First of all the effects of excessive droughts at each stage of the plant can be estimated from the experimental data given in Part I, and will be found to harmonize as well as could be expected with the results of actual experience as given in Part II:

(b) The effect of severe unusual droughts, or heat, or cold, or moisture are ordinarily felt over relatively small portions of the country, so that the average result is small in comparison with the whole crop available in the country; for instance, in 1890, in Kansas and Nebraska the corn harvest was one-half of its usual amount and almost the same in 1887, reckoning, of course, the yield per acre, but this and the corresponding small yields in a few other States represent only an inappreciable percentage of loss to the country at large.

(5) The studies of the effect of climate on the daily development of sugar in beets, sugar cane, or sorghum, or on the nutritious harvest of grass and cereals has shown the approximate best dates for harvesting these crops.

(6) The studies of the physiological importance of the leaves of beets will eventually show whether these should be trimmed or how they should be treated in order to stimulate the production of sugar. As the pruning of hop vines and grapevines stimulates the ripening and increases the amount of the crops, and as the plucking of the tassels from the maize apparently increases that crop, and as the plucking of the flowers and balls from the potato vines increases the growth of the tubers, so doubtless in many other ways the methods of

cultivation may be made to simulate the effects of a favorable climate, so that in general we are justified in the conclusion that while uncultivated plants and their fruits are wholly dependent on the weather, yet methods will be found by which we may render the harvests from cultivated plants largely independent of the weather.

(7) The data here collected demonstrate that the richness of the soil determines the amount of the annual cereal crop more than does the climate. The latter determines principally the dates of sowing, ripening, and the immunity from early or late frosts or the possibility of bringing the plant to maturity.

(8) We see that rain or irrigation water, so necessary as the medium for bringing the nitrogenous molecules from the soil up into the seed cells of the plant, also by drainage and seepage carries away any such molecules if these are present as earths or manures, whereas if these are present in living microbic or rotting leguminous cells they are far more available for plant use. The best method by which the nitrogen of the free air is thus made available for agriculture is elaborated in chapters VIII and IX.

(9) From the data now at hand I should say that the yield per acre for any one of the ten principal crops whose statistics are here given has probably never been either increased or diminished by 50 per cent of the normal yield per acre by climatic influences alone over any large region, such as 100 square miles, and, further, that the total annual harvest for any given crop in the United States is not likely to be diminished 5 per cent by the occurrence of an inclement season in some one portion of the country.

The detailed comparison of the climate for each season with the crop for that season has become practicable to me only since completing the table of statistics in this chapter, and it is as yet too soon to anticipate all the results that will follow therefrom.

NOTE.—As these statistical tables are very voluminous and only extend to the year 1890 their publication has been deferred until they can be brought up to date. They will probably form a continuation of this present text.—C. A.



## PART IV.

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### Chapter XIV.

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Bulletin No. 37.—W. B. No. 349.

Price 10 cents.

U. S. DEPARTMENT OF AGRICULTURE,  
WEATHER BUREAU.

# RECENT PRACTICE IN THE ERECTION OF LIGHTNING CONDUCTORS.

Prepared under the direction of WILLIS L. MOORE, Chief U. S. Weather Bureau.

BY

ALFRED J. HENRY,  
PROFESSOR OF METEOROLOGY

WASHINGTON:  
WEATHER BUREAU  
1906.

Sci 7.115



**From the  
U. S. Government.**

## LETTER OF TRANSMITTAL.

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U. S. DEPARTMENT OF AGRICULTURE,  
WEATHER BUREAU,  
*Washington, D. C., February 2, 1906.*

HON. JAMES WILSON,  
*Secretary of Agriculture.*

SIR: I have the honor to transmit herewith a report entitled Recent Practice in the Erection of Lightning Conductors, by Alfred J. Henry, Professor of Meteorology, and to recommend its publication as a bulletin of the Weather Bureau.

Very respectfully,

WILLIS L. MOORE,  
*Chief U. S. Weather Bureau.*

Approved.

JAMES WILSON, *Secretary.*



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# RECENT PRACTICE IN THE ERECTION OF LIGHTNING CONDUCTORS.

By ALFRED J. HENRY, Professor of Meteorology.

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It can not be said that there is any uniformity of practice in the erection of lightning conductors in the United States. In large cities, one occasionally sees a residence on which they have been installed, more often a church, but very rarely a public building. The Federal Government does not install lightning conductors on any of the buildings it erects. In the case of powder magazines, however, the Ordnance Department of the Army provides a very complete system of protection from lightning. So too in the case of overhead electric power circuits that enter Federal buildings care is taken to protect the building from flashes that may come over the line. That the Government engineers are not without appreciation of the value of lightning conductors is evinced by the very complete system of protection installed upon the Washington Monument in 1885. In the application of lightning conductors to the monument the engineers in charge were guided by sound principles, and as might justly be expected, established a system of protection that has successfully performed its functions for more than 20 years. A detailed description is here reproduced since the original document is now inaccessible to the general public. (Senate Ex. Doc. No. 6, 49th Cong. 1st Session.)

## LIGHTNING CONDUCTORS ON THE WASHINGTON MONUMENT.

The lightning conductors, as established for the monument, were commenced in January, 1880, and were finished in January, 1885. These conductors consist of 4 hollow wrought-iron Phoenix columns standing in the well of the shaft, and which support the elevator machinery and guide the car. These columns are 6 inches in exterior diameter, five-eighths of an inch in thickness, and are made up of sections 20 feet in length fastened together with long inside couplings, which fit tightly into the columns, and are fastened to them by 16 screw bolts. The bottoms of these 4 columns rest upon and are bolted to cast-iron shoes, which in turn stand upon the floor of the large drum pit beneath the floor of the monument. The shoes are connected to three-quarter inch soft copper rods led to the bottom of a well in the center of the foundation. This well is 32 feet 10 inches in depth below the bottom of the drum pit, and 15 feet 8 inches below the bottom of the masonry foundation, and the water stands in it permanently 2 feet 8 inches above its bottom. After the copper rods were inserted the well was filled with clean sharp sand for a depth of 15 feet 8 inches, or up to the level of the bottom of the old rubble-stone foundation of the monument. These 4 columns so arranged at their bases, and always projecting above the top of the shaft, were continually lengthened as the building of the shaft progressed, and for the 5 summers during which the masonry was in progress acted as the lightning conductors of the

edifice. No disruptive discharge of electricity was experienced during those 5 years.

When the walls were completed, in December of 1884, and the upper extremities of the columns were covered in by the marble pyramidion, 4 copper rods, three-quarters of an inch in diameter, were run, one from each column, to the top stone, and there united in a  $1\frac{1}{2}$  inch copper rod, which passing vertically through the stone, was screwed into a solid metal terminal of aluminum. This metal was selected for the terminal because of its whiteness, and the probability that its polished surfaces would not tarnish upon exposure to the air. It was a square pyramid in shape, similar to the pyramidion of the obelisk, and, fitting upon the top stone, completed the apex. This terminal weighed 100 ounces, and was 8.9+ inches in height and 5.6+ inches in width at the base. The angle at the vertex between 2 opposite sides was about  $34^{\circ} 48'$ .

The conductors, as above described, when tested gave an electrical resistance of one-tenth of an ohm from the tip of the terminal to the copper rods at the base, and two and two-tenths ohms for the ground connections, making a total resistance of two and three-tenths ohms for the conductor. The system was entirely completed and connected on January 20, 1885.

On the 5th of April, 1885, during the passage of a heavy thunder cloud over the monument, at least 5 immense sparks or bolts of electrical light were seen within a period of 20 minutes to flash between the terminal and the cloud, without audible sound to the observers. A careful examination of the conductors and shaft after these phenomena failed to reveal any effects from these discharges.

On the 8th of June, however, during a thunderstorm, a disruptive discharge was seen to pass between the summit of the pyramidion and the cloud. Upon examining the structure a crack was discovered in the stone on the north face of the pyramidion just under the top stone, extending through the block in a line nearly parallel to the northeast corner, and about eight and one-half inches from it. The fragment was pressed outwards about three-quarters of an inch at its bottom, chipping a small piece off the lower corner of the top stone into which it was locked, and was easily forced back to place and bolted to the solid stone from which it had been torn.

Under the circumstances of this damage, and to devise if possible some plan by which the obelisk could be more effectually protected from lightning, Professors H. A. Rowland, of the Johns Hopkins University, Simon Newcomb, of the United States Navy, and T. C. Mendenhall, of the United States Signal Service, were invited to inspect the conductors and recommend any modifications in them, which in their judgment would be proper for the end required. This they kindly consented to do, and after a careful examination recommended, in substance, that the interior conductors should be connected with a system of rods and a greater number of points to be located upon the exterior of the pyramidion. The additions, as devised by them, consist of 4 one-half inch copper rods, fastened by a band to the aluminum terminal and led down the corners to the base of the pyramidion; thence passing through the masonry they extend inward and are joined to the iron columns above described. As these exterior rods are each over 60 feet long, they are also connected at two intermediate points of their lengths with the iron columns by means of copper rods one-half and three-quarters of an inch, respectively, furnishing sixteen rods in all connecting the exterior system of conductors with the interior conducting columns. Where the exterior rods upon the corners cross the eleven highest horizontal joints of the masonry of the pyramidion, they are connected to each other all around by other copper rods sunk into those joints. All of these exterior rods, couplings, and fittings are gold plated, and are studded at every 5 feet of their lengths with copper points 3 inches in length, gold plated and tipped with platinum. There are 200 of these points in all. \* \* \*

## LIGHTNING CONDUCTORS IN URBAN DISTRICTS.

In urban districts the application of lightning conductors to farm and residence buildings is much more common than in the larger towns and cities. Whether or not lightning conductors shall be installed on buildings is generally determined by the individual judgment of the owner. So far as known, the architects' plans, when such are used, do not provide for lightning conductors.

### APPARENT DECREASE IN USE OF LIGHTNING CONDUCTORS.

It seems probable that there has been a decided falling off in the use of lightning conductors within the last 30 years. According to the United States Census statistics, there were, in 1860, twenty establishments manufacturing lightning rods, which turned out a product valued at \$182,750. In 1870 the number of establishments had risen to 25 and the value of the products to \$1,374,631. In the next decade the number of establishments fell to 20 and the value of the product to \$801,192, and finally in 1890 the number of establishments rose to 22, but the value of the product diminished to \$483,296. At the census of 1900 the classification in vogue from 1860 to 1890 was abandoned and lightning rods were tabulated in the general classification "Foundry and Machine Shop Products." There are no means of determining absolutely whether the large decrease in the value of the manufactured product from 1870 to 1890 marks a decline in the use of lightning conductors; certain it is, however, that the "Lightning Rod Man" is not so much in evidence as he was in the early seventies.

The possibilities and the limitations of a properly installed lightning rod are fully set forth on the pages which follow. In general the conclusions therein reached are in close accord with those of the Weather Bureau officials who have given attention to the subject. In large cities the use of lightning rods is not imperative owing to the prevalence of modern steel structures and in general buildings with metal roofs. For buildings that stand isolated in the open country the prudent course would be to install thereon a system of protection from lightning. The extent to which the building should be protected and naturally the expense of installation should bear some definite relation to the value of the building. If the building is insured against loss by fire or lightning, it would not seem advisable to go to the additional expense of erecting lightning rods. In any event the final decision must be reached by the owner of the building. In arriving at his decision he should be guided by the fact that, while absolute security from damage by lightning is attainable only with great difficulty and considerable expense, a reasonable degree of protection can be secured by very simple means, provided the system of protection be devised and erected by a thoroughly competent person.

## REPORT OF LIGHTNING RESEARCH COMMITTEE. (GREAT BRITAIN.)

There recently appeared in the Journal of the Royal Institute of British Architects, Third Series, Volume XII, No. 13, a report made by the Lightning Research Committee, a committee that was formed for the purpose of obtaining trustworthy information on disasters suffered by buildings from lightning, of investigating causes of failure of lightning conductors to protect, and finally of suggesting, if possible, improved means of protection. A short preface to the report was written by Sir Oliver Lodge, F. R. S. Both the preface and the report of the committee contain so much information of value to American architects and builders that a very full abstract is here given. Acknowledgment is made of our indebtedness to the committee which formulated the report, as well as to the Journal of the Royal Institute of British Architects, which published it.

## REPORT OF THE LIGHTNING RESEARCH COMMITTEE. (GREAT BRITAIN.)

## PREFACE.

By SIR OLIVER LODGE, F. R. S.

Since the report, many years ago, of the Lightning Rod Conference knowledge of the subject has considerably increased and the effect of self-induction, which then was completely ignored, has been taken into account and understood. The main differences between what is recommended to-day and what was considered sufficient then depend on the recognition of the influence of self-induction or electrical inertia. Then electricity was treated as if it had no inertia, and as if all that was necessary was to get it from the clouds to the earth as quickly and easily as possible by the shortest path, which may be called the drain-pipe theory. It was supposed that it would always take the easiest path, and that the easiest path would protect all others. Attention was directed to the quantity of electricity which had to be conveyed down, and to nothing else.

Now, however, it is perceived that it is not so much quantity of electricity that has to be attended to as electrical energy; that this electrical energy is stored between clouds and earth in dangerous amount, and that our object should be to dissipate it not as quickly but as quietly as possible. A sudden dissipation of energy is always violent. No one in his senses wishes to stop a fly wheel or a railway train suddenly; sudden or hasty dissipation is not what is wanted. Gun cotton possesses a store of potential energy locked up in it to a dangerous extent; if it be dissipated suddenly, as by percussion, a violent explosion results; but if it be dissipated gradually, as by a flame, the energy is got rid of without much damage, beyond the liability to fire. An armor plate may be able to stop a cannon ball quickly, but a heap of sand or loose earth does it more safely, because more gradually.

So it is exactly with the store of energy beneath an electrified cloud or between one cloud and another. A lightning conductor of perfect conductivity, if struck, would deal with the energy in far too rapid and sudden a manner, and the result would be equivalent to an explosion. A conductor of moderately high resistance, such as an iron wire, would get rid of it in a slower and therefore much safer and quieter manner, though with too thin a wire there may be risk of fire.

The rush in any case, however, is likely to be rather violent, and, like an avalanche, it will not take the easiest path provided for it, as if it were a trickling stream, but will crash through obstacles and make its own path, some portions

of it taking paths which would be quite unexpected. Hence, no one path can be said to protect others, and the only way to protect a building with absolute completeness is to inclose it wholly in metal. An invisible cage or framework of iron wires, however, descending vertically down its salient features, with the utilization of any metal in its construction, suffices for all practical purposes, unless the building is a powder magazine.

The effect of *points*, and of rain also, in gradually dissipating a charge, and thereby contributing to safety, has long been understood; but the feature which has not been known is that there are cases where points are wholly inoperative, viz, when the energy is stored between cloud and cloud, instead of between cloud and earth, and when the initial discharge takes place from one cloud to another; then the lower cloud is liable suddenly to overflow to earth through a region in which there was no previous preparation, and where any number of points, or a rain shower, or any other form of gentle leak, would have been quite inoperative. Then can a violent discharge occur to even the sharpest point; and a hot column of air, such as rises up a chimney, is even preferred to a conductor. These are the flashes against which points and rain are no protection, and these are probably those which do the most damage to protected buildings. But it must be understood that when a flash does occur through a building, it matters little which kind of flash it is—both can be equally sudden and violent—but if the building is well provided with points, the first or prepared kind is not likely to occur, save in exceptional cases, the dangerous liability is then the sudden or overflow variety of flash.

These, then, are the two points of novelty :

1. The possible occurrence of a totally unprepared-for and sudden flash in previously unstrained air, by reason of overflow from a discharge initiated elsewhere, what is called the *B* spark, occurring as the secondary result of an *A* spark.

2. The effect of electrical inertia or momentum, so that the discharge is not a simple leak or flow in one direction, but a violent oscillation and splash or impulsive rush, much more like an explosion, and occurring in all directions at once, without much regard to the path which had been provided for it; no more regard, in fact, than is required to enable the greater part of it to take the good conductors, and to prevent any part of it from being able to enter a perfectly inclosed metallic building.

Even a small lateral fraction of a flash is able, however, to ignite gas if there is a leak, or even to *make* a leak at a "compo"-pipe where it is crossed by a bell wire, and then ignite it; hence, after a building has been struck, careful watch should be kept for some time against the danger of fire.

The amount of protection to be allotted to any building is no doubt analogous to the question of insurance generally; that is to say, the amount of premium it is desired to pay may be compared with the capital at stake and the risk run; and this is doubtless a matter for individuals and public bodies to consider for themselves. What the committee can do is to make a study of cases of damage occurring to buildings which on the old lines were supposed to be protected, to tabulate them as below, and to ask for carefully recorded observations; they can also draw up such hints and suggestions as may be of use to architects whose clients desire their buildings to be protected in a more thorough, but not necessarily a more expensive manner.

These objects, and these attempts at being useful, explain the existence of the present report.

#### OBSERVATIONS AND SUGGESTIONS.

It has been pointed out by Sir Oliver Lodge that lightning discharges are of two distinct characters, which he has named the *A* flash and the *B* flash, respectively.



The *A* flash is of the simple type which arises when an electrically charged cloud approaches the surface of the earth without an intermediate cloud intervening, and under these conditions the ordinary type of lightning conductor acts in two ways: first, by silent discharge; and secondly, by absorbing the energy of a disruptive discharge. In the second type, *B*, where another cloud intervenes between the cloud carrying the primary charge and the earth, the two clouds practically form a condenser; and when a discharge from the first takes place into the second the free charge on the earth side of the lower cloud is suddenly relieved, and the disruptive discharge from the latter to the earth takes such an erratic course *that no series of lightning conductors of the hitherto recognized type suffice to protect the building.*

On the 28th of May, 1904, an interesting demonstration of the action of *A* and *B* flashes, respectively, was given by Sir Oliver Lodge before members of the committee and others interested in these researches. A thin sheet of metal mounted on nonconducting standards represented the cloud, which was charged at will from a Leyden jar. The "cloud" was so arranged that the model lightning conductors could have their points brought nearer to or farther from its under surface by shifting their positions on the table. Conductors of copper, iron, and wet string were experimented with. The disruptive discharge to the copper proved to be by far the loudest and most intense of the three. The iron took the flash with less noise, the wet string, with hardly any; yet when the discharge passed through it the other and apparently better conductors were not affected. The experiments tended to demonstrate that iron is in many situations a very useful material for lightning rods, as the effective energy of a flash of lightning is rapidly dissipated in iron. This metal, however, unfortunately oxidizes rapidly in towns and smoky districts, and the use of copper as a material for a lightning rod is still recommended for main conductors in relatively inaccessible positions, although iron is electrically preferable.

A consideration of the descriptions of recent foreign practice given in Appendix B, and of the cases which appear in the summary of damage, Appendix A, (not here reprinted) justifies the following general observations:

It is probable that with few exceptions buildings in this country are not in reality efficiently protected against the effects of a *B* flash, although in many cases the lightning conductors may be said to have at least partially fulfilled their purpose by carrying off the more violent portion of a discharge, and that without them greater damage would have occurred in many of the cases reported.

Some of these observations throw a very interesting light on the effects due to the oscillatory character of lightning discharges. For instance, a discharge takes place over a lightning rod which may be in contact with, or approach closely to, the metallic portions of a roof. Powerful electrical oscillations are set up in the latter conductors, and dangerously high electrical pressure may be generated on the distant ends of these conductors. If at these points they were connected to earth the pressure would be relieved, and the discharge harmlessly dissipated. Without this safe path the discharge may break away into the down pipes, or may pierce the roof to reach internal conductors. Cases which appear to indicate successive or simultaneous flashes may be due to a single flash setting up these oscillations.

In some cases the damage done to a building by an *A* flash is not necessarily due to the primary discharge. A lateral discharge occasionally occurs which frequently causes minor, though in some cases serious, damage owing to falling materials.

Many of the reports of damage to unprotected buildings show that the lightning discharge followed the path of wire ropes, metallic pipes, and other conductors, and that the damage to the structure occurred at the breaks in continuity at the upper and lower terminals, respectively.

It may be considered that a lightning conductor of the ordinary type, if properly constructed, affords an undefined area of protection against *A* flashes, but it can not be said to have any protective area against *B* flashes.

Absolute protection of the whole of a building could only be assured by inclosing the structure in a system of wirework—a contrivance, in fact, of the nature of a bird cage. This should be well connected at various points to earth, as nearly all buildings have gas and water pipes and other metallic conductors in their interiors which are likewise earthed. For structures intended for the manufacture or storage of gunpowder and other explosives the adoption of this bird cage protection would be justified on the score alone of public safety. Architectural considerations prevent the adoption of such a method in its entirety for ordinary buildings. There is no doubt, however, that practically perfect protection may be assured by a judicious modification of the existing practice of erecting single lightning rods, especially in the case of extensive and lofty buildings that project well above surrounding structures or that stand isolated in the open country.

It is obvious that the extent to which the building should be protected and the expense to be incurred in this protection must bear some definite relation to the importance or cost of the building itself. In cases where protection is considered desirable, but heavy expense is not justified, two or more lightning rods might be erected in the ordinary manner, these being connected by a horizontal conductor, and the metal portions of the roof and the rain water down pipes should be metallically connected and well earthed.

Tall chimney shafts are not efficiently protected against a *B* flash by an ordinary single lightning rod, as a hot column of smoke issuing from a chimney conducts as well or even better than a rod. A circular band should surround the top of the shaft; four or more conductors should be raised above the latter in the form of a coronal, or the continental practice of joining the elevation rods together, so as to form an arch over the chimney, may be employed with advantage. One or, preferably, two lightning rods should extend from this circular band to the earth in the manner described below.

As most buildings contain systems of gas and water pipes, a good earth for the lightning conductors is highly desirable. In the case of a stove inside a building with a metallic stovepipe carried outside the stove should be earthed and a wire be led from the pipe to earth outside, or to the nearest conductor.

The various cases noted by the committee show that while even single conductors tend to diminish the damage done to buildings by lightning no reliance can be placed on an area of protection. Judging by the latest foreign practice, continental experience appears to be confirmatory of this view (see Holland, Hungary, and Germany, Appendix B). In churches and other buildings with spires and towers the lower projections should also be protected, even if forming part of the salient features of the building.

No cases of damage to modern steel frame structures have come under the notice of the committee. The ordinary method of construction, however, in this country does not provide full protection. In many cases the steel columns stand on stone foundations and the metal is not carried deep enough for effective earthing. The metal columns ought to be earthed at the time of construction.

In the opinion of the committee, the methods advocated in the Report of the Lightning Rod Conference still hold good, provided arrangements are made to keep the earth permanently moist. The committee therefore deems it convenient to print here the rules issued by the Lightning Rod Conference in 1882, supplementing them with observations and suggestions of their own based on the results of their recent researches.



**RULES FOR THE ERECTION OF LIGHTNING CONDUCTORS, AS ISSUED BY THE LIGHTNING ROD CONFERENCE IN 1882, WITH OBSERVATIONS THEREON BY THE LIGHTNING RESEARCH COMMITTEE, 1905.**

[NOTE. — Paragraphs beginning with odd numbers refer to Lightning Rod Rules, 1882; those with even numbers to Lightning Research Committee's observations, 1905.]

1. **POINTS.**—The point of the upper terminal should not be sharp, not sharper than a cone of which the height is equal to the radius of its base. But a foot lower down a copper ring should be screwed and soldered on to the upper terminal, in which ring should be fixed three or four sharp copper points, each about 6 inches long. It is desirable that these points be so platinized, gilded, or nickel plated as to resist oxidation.

2. It is not necessary to incur the expense of platinizing, gilding, or electroplating. It is desirable to have three or more points beside the upper terminal, which can also be pointed; these points must not be attached by screwing alone, and the rod should be solid and not tubular.

3. **UPPER TERMINALS.**—The number of conductors or points to be specified will depend upon the size of the building, the material of which it is constructed, and the comparative height of the several parts. No general rule can be given for this, but the architect must be guided by the directions given. He must, however, bear in mind that even ordinary chimney stacks, when exposed, should be protected by short terminals connected to the nearest rod, inasmuch as accidents often occur owing to the good conducting power of the heated air and soot in the chimney.

4. This is dealt with below in suggestion 3 (page 16).

5. **INSULATORS.**—The rod is not to be kept from the building by glass or other insulators, but attached to it by metal fastenings.

6. This regulation stands.

7. **FIXING.**—Rods should preferentially be taken down the side of the building which is most exposed to rain. They should be held firmly, but the holdfast should not be driven in so tightly as to pinch the rod or prevent the contraction and expansion produced by changes of temperature.

8. In most cases it would be advantageous to support the rods by holdfasts (which should be of the same metal as the conductor) in such a manner as to avoid all sharp angles. The vertical rods should be carried a certain distance away from the wall to prevent dirt accumulating and also to do away with the necessity of their being run round projecting masonry or brickwork.

9. **FACTORY CHIMNEYS.**—These should have a copper band around the top, and stout, sharp copper points, each about one foot long, at intervals of two or three feet throughout the circumference, and the rod should be connected with all bands and metallic masses in or near the chimney. Oxidation of the points must be carefully guarded against.

10. As an alternative, the rods above the band might with advantage be curved into an arch provided with three or four points. It is preferable that there should be two lightning rods from the band carried down to earth in the manner previously described. Oxidation of the points does not matter.

11. **ORNAMENTAL IRONWORK.**—All vanes, finials, ridge ironwork, etc., should be connected with the conductor, and it is not absolutely necessary to use any other point than that afforded by such ornamental ironwork, provided the connection be perfect and the mass of ironwork considerable. As, however, there is a risk of derangement through repairs, it is safer to have an independent upper terminal.

12. Such ironwork should be connected as indicated below in suggestion 3. In the case of a long line of metal ridging a single main vertical rod is not sufficient, but each end of the ridging should be directly connected to earth by a rod. Where the ridge is nonmetallic a horizontal conductor (which need not be of large sectional area) should be run at a short distance above the ridge and be similarly connected to earth.

13. **MATERIAL FOR ROD.**—Copper, weighing not less than 6 ounces per foot run, and the conductivity of which is not less than 90 per cent of that of pure copper, either in the form of tape or rope of stout wires—no individual wire being less than No. 12 B. W. G. Iron may be used, but should not weigh less than  $2\frac{1}{2}$  pound per foot run.

14. The dimensions given still hold good for main conductors. Subsidiary conductors for connecting metal ridging, etc., to earth may with advantage be of iron and of a smaller gage, such as No. 4 S. W. G. galvanized iron. The conductivity of the copper used is absolutely unimportant, except that high conductivity increases the surges and side flashes, and, therefore, is positively objectionable. It is for that reason that iron is so much better.

15. **JOINTS.**—Although electricity of high tension will jump across bad joints, they diminish the efficacy of the conductor; therefore every joint, besides being well cleaned, screwed, scarfed, or riveted, should be thoroughly soldered.

16. Joints should be held together mechanically as well as connected electrically, and should be protected from the action of the air, especially in cities.

17. **PROTECTION.**—Copper rods to the height of 10 feet above the ground should be protected from injury and theft by being inclosed in an iron pipe reaching some distance into the ground.

18. This regulation stands.

19. **PAINTING.**—Iron rods, whether galvanized or not, should be painted; copper ones may be painted or not according to architectural requirements.

20. This regulation stands.

21. **CURVATURE.**—The rod should not be bent abruptly round sharp corners. In no case should the length of the rod between two points be more than half as long again as the straight line joining them. Where a string course or other projecting stonework will admit of it, the rod may be carried straight through, instead of round the projection. In such a case the hole should be large enough to allow the conductor to pass freely, and allow for expansion, etc.

22. The straighter the run the better. Although in some cases it may be necessary to take the rod through the projection, it is better to run outside, keeping it away from the structure by means of holdfasts, as described above.

23. **EXTENSIVE MASSES OF METAL.**—As far as practicable it is desired that the conductor be connected to extensive masses of metal, such as hot-water pipes, etc., both internal and external; but it should be kept away from all soft metal pipes, and from internal gas pipes of every kind. Church bells inside well-protected spires need not be connected.

24. It is advisable to connect church bells and turret clocks with the conductors.

25. **EARTH CONNECTIONS.**—It is essential that the lower extremity of the conductor be buried in permanently damp soil; hence proximity to rain-water pipes, and to drains, is desirable. It is a very good plan to make the conductor bifurcate close below the surface of the ground, and adopt two of the following methods for securing the escape of the lightning into the earth. A strip of copper tape may be led from the bottom of the rod to the nearest gas or water *main*—not merely to a lead pipe—and be soldered to it; or a tape may be soldered to a sheet of copper 3 feet by 3 feet and  $\frac{1}{8}$ -inch thick, buried in permanently wet earth, and surrounded by cinders or coke; or many yards of the tape may be laid in a trench filled with coke, taking care that the surfaces of copper are, as in the previous cases, not less than 18 square feet. Where iron is used for the rod, a galvanized-iron plate of similar dimensions should be employed.

26. The use of cinders or coke appears to be questionable owing to the chemical or electrolytic effect on copper or iron. Charcoal or pulverized carbon (such as ends of arc-light rods) is better. A tubular earth consisting of a perforated steel spike driven tightly into moist ground and lengthened up to the surface, the conductor reaching to the bottom and being packed with granulated charcoal, gives as much effective area as a plate of larger surface, and can easily be kept moist by connecting it to the nearest rain-water pipe. The resistance of a tubular earth on this plan should be very low and practically constant.

27. **INSPECTION.**—Before giving his final certificate the architect should have the conductor satisfactorily examined and tested by a qualified person, as injury to it often occurs up to the latest period of the works from accidental causes, and often from carelessness of workmen.

28. Inspection may be considered under two heads:

A. The conductor itself.

B. The earth connection.

A. Joints in a series of conductors should be as few as possible. As a rule they should only be necessary where the vertical and horizontal conductors are connected, and the main conductors themselves should always be continuous and without artificial joints. Connections between the vertical and horizontal conductors should always be in places readily accessible for inspection. Visible continuity suffices for the remainder of the circuit. The electrical testing of the whole circuit is difficult, and needless.

B. The electrical testing of the earth can in simple cases be readily effected. In complex cases, where conductors are very numerous, tests can be effected by the provision of test clamps of a suitable design.

29. **COLLIERIES.**—Undoubted evidence exists of the explosion of fire-damp in collieries through sparks from atmospheric electricity being led into the mine by the wire ropes of the shaft and the iron rails of the galleries. Hence the head gear of all shafts should be protected by proper lightning conductors.

#### SUGGESTIONS OF THE COMMITTEE.

The investigations of the committee warrant them in putting forward the following practical suggestions:

1. Two main lightning rods, one on each side, should be provided, extending from the top of each tower, spire, or high chimney stack by the most direct course to earth.

2. Horizontal conductors should connect all the vertical rods (a) along the ridge, or any other suitable position on the roof; (b) at or near the ground.

3. The upper horizontal conductor should be fitted with aligrettes or points at intervals of 20 or 30 feet.

4. Short vertical rods should be erected along minor pinnacles and connected with the upper horizontal conductor.

5. All roof metals, such as finials, ridging, rain water, and ventilating pipes, metal cowls, lead flashing, gutters, etc., should be connected to the horizontal conductors.

6. All large masses of metal in the building should be connected to earth either directly or by means of the lower horizontal conductor.

7. Where roofs are partially or wholly metal lined they should be connected to earth by means of vertical rods at several points.

8. Gas pipes should be kept as far away as possible from the positions occupied by lightning conductors, and as an additional protection the service mains to the gas meter should be metallically connected with house services leading from the meter.

(Signed)

JOHN SLATER, *Chairman*,  
E. ROBERT FESTING,  
OLIVER LODGE,  
J. GAVEY,  
W. N. SHAW,  
A. R. STENNING,  
ARTHUR VERNON,  
KILLINGWORTH HEDGES,  
*Honorary Secretary*,  
G. NORTHOVER, *Secretary*.

## APPENDIX B.

## LATEST PRACTICE ABROAD.

*Holland.*

The following is translated from the Dutch of the very complete and valuable report made by Dr. D. van Gulik at the request of the Dutch Academy of Science, which has just been published under the title of Further Inquiries in Regard to the Protection of Buildings from Lightning (Haarlem, 1905):

1. Lightning conductors serve to lessen the risk of fire and of serious damage for the buildings protected by them, and to reduce considerably the danger to life for those who inhabit the buildings. Whether the risk of a building being struck by lightning is also lessened by the installation of points or bundles of points is very doubtful. Where, therefore, economy is an object these may be first dispensed with.

2. In protecting buildings from lightning we must bear in mind that, contrary to what we notice in the case of constant electric currents—

(a) Lightning shows a great tendency to distribute itself over such conductors as may be present, and in so doing to pay little heed to the electrical resistance of the conductor.

(b) That it finds no great difficulty in making its way, often for a considerable distance, through the air or through any other good conducting medium.

(c) That it prefers to move, as far as possible, in a straight line, and that, therefore, sharp turns or spiral windings in conductors present hindrances which, in view of the properties mentioned in paragraphs *a* and *b*, readily lead to lateral discharges.

Absolute security is not attainable or attainable only with great difficulty, and in any case at considerable expense. On the other hand a quite satisfactory degree of protection can be secured by very simple means.

3. The greater the importance attached to the preservation of a building and its contents the more perfect can the system of conductors be made, and thus a higher coefficient of safety is obtained by increased expenditure.

4. The conductors at present used in Holland secure a fairly high degree of safety in the case of houses with tiled or slated roofs, as they reduce the risk of fire when struck to an average of between one-sixth or one-seventh. Statistics show, however, that the lightning frequently diverges from them and may even strike the buildings without touching the terminal rods. Moreover, the cost of installation is so great that many people are deterred thereby from having these useful appliances fitted. Certain general improvements and simplifications may, however, be pointed out, by means of which the conductors would, even at a lower cost, better answer the purpose for which they are intended.

5. The *improvements* are in the main as follows:

(a) All salient positions liable to be struck should be provided with terminals in the form of short rods or wires, and the roof should be girt round on all sides by wire conductors. This would take the place of the high terminal rods with their imaginary cone of safety.

(b) Several conductors running to the earth should be fitted.

(c) The system of conductors should be connected with any extensive metallic mass present in the building, if necessary at more points than one. In the case of gas and water pipes such connection is absolutely necessary.

6. The principal *simplifications* may be summed up thus:

(a) High terminal rods should be abolished, as it is difficult to fix them firmly enough.

(b) Copper, which is the material generally used for conductors and earth connections, should be replaced by iron. This, if well galvanized, will resist atmospheric influences for a very long time and can, moreover, be easily protected by a coat of paint.

(c) The thickness of the conductors should be reduced. In support of this we may adduce the evidence of the ordinary telegraph wire, which is seldom, if ever, found to be melted, except at the point where it is struck. Even in providing for extreme cases we should not lose sight of the fact that a wire will do its duty even though it succumbs to the force of the stroke.

(d) The metallic constructional portions of the building should be pressed into service as conductors. By this means either the conducting system is extended, with a consequent increase in the margin of safety, or the use of special conductors may be partly dispensed with. This last expedient proves a ready means, in the case of special classes of buildings, of providing quite efficient conductors at a trifling cost. It is not necessary that there should be metallic contact between the metal constructions provided that they overlap one another over an area of 10 square centimeters.

7. In making earth connections too much importance is often attached to reaching the ground water level, while on the other hand too little care is taken to secure a good connection between the conductor and the uppermost layer of soil. By paying attention to this a considerable saving may in some cases be made in the cost of earth contact. In isolated cases where connection with underground pipes, etc., is possible, no special earth connection is necessary.

8. When building houses it is desirable that the conductors should always be marked on the plans. This makes their installation easier and reduces the cost. Moreover, it enables architects to exclude from their plans constructions which would tend to increase the risk of fire in the event of the house being struck by lightning.

9. Special precautions are necessary in the case of thatched roofs. These consist mainly in keeping the conductors some distant away from the roof and in making the wire of such thickness that it shall not be destroyed at the point where it is struck by lightning. If this be done, a high degree of safety is attainable even in the case of thatched roofs.

### *Hungary.*

Through the good offices of the Rector of the Royal Joseph Polytechnical University, Budapest, Dr. Moritz von Hoór kindly favored the committee with the following remarks concerning the precautions against lightning now coming into use in Hungary, showing the method of their installation and their efficacy as proved by experience:

Up to the year 1892, in Hungary as well as in other countries, lightning conductors with collecting points according to the Franklin system were the only ones in use. Here, as elsewhere, the view was universally accepted that absolute security for the efficiency of lightning conductors was afforded by the largest possible cross section of the lightning rod, by a slight change of the collecting apparatus, and by a good earth connection. It was held, therefore, that a conductor had been rightly set up when the collecting point and the earth had been connected by strong copper wires or cables, and care had been taken for a good earth contact.

Experience of such lightning conductors, however, as well as observations systematically taken in England and the English colonies, and in Germany, proved that lightning rods on this principle did not answer their purpose, and in particular that the directions as to the area of protection of the conductor and the relation between height and base of the protected zone were of no practical value and quite baseless.



It was repeatedly observed that there were lateral discharges from the conductor in the direction of the metal parts (badly connected apparently with the earth), that sparks leaped over curves in the conduction apparatus, and in general that buildings and other objects protected by the collecting points suffered damage from lightning, though to a far less extent, as shown by statistics, than objects altogether unprovided with lightning conductors.

Prof. Moritz von Hoór, following up the work of Hertz and Lodge, was the first in our country to treat this question theoretically and experimentally in a scientific manner on the basis of the new principles, and he was the first here to suggest the abandonment of the conductors with collecting points, and the introduction of contour conductors without collecting points similar to Faraday's parrot cage.

Leopold Stark, chief engineer of Messrs. Ganz & Co., has since made an exhaustive study of this question, and has worked out various practical plans for cage conductors, with a special view to their application to the protection of agricultural objects peculiarly exposed to risks from lightning (cf. *Villámhárítók különös tekintettel mezőgazdasági épületekre*, irta: Stark Lipót gépészmérnök, Budapest, Fővárosi Nyomda, 1903).

For some years now, as a result of these works and of the agitation started by the above-mentioned scientists, cage lightning conductors of this kind have been largely in use with us, both on town buildings and on agricultural objects. They consist, as Sir Oliver Lodge, and, long before him, Faraday, suggested, of barbed wire, or strong iron wire, or sheet iron bands, which, following the contours of the roof and building or other objects conduct to separate earth connections or to connections joined underground by a circular conducting wire.

The cost of such conductors is with us hardly more than that of the conductors with gilt collecting points and copper conducting wires, and they have been found admirably efficacious as might have been deduced from theoretical reasoning, so that the military authorities both in Austria and Hungary have had all magazines of explosives protected in this manner.

Special care is taken, in setting up these cage conductors, to avoid the sharp curves arising from a sudden change in the direction of the earth conductors, so as to reduce as far as possible the self-induction of the earth connection.

Importance is also attached to good earths, but experience shows that if the cage arrangement is well carried out and the number of cage wires not too scanty, even without a very good earth connection, the conductor still works satisfactorily.

At present both the cage and the Franklin collecting point systems are in use with us; but of late years, especially for agricultural objects, the cage system is coming more and more in vogue, and probably in a short time all the new conductors will be of this kind:

#### *Germany.*

The following is extracted from the Regulations of the Electro-Technical Society of Berlin, issued in 1901:

1. The lightning receivers should consist of vertical points. The points of towers or gables, edges of the ridge of the roof, tops of chimney stacks, and other high parts of buildings should be converted into receivers or be provided with suitable receivers. The conductors should be in metallic connection with the receivers and the earth; they should go round the building, especially in the roof, and if possible on all sides, and then be led from the receivers to the ground by the most direct route, avoiding as much as possible all sharp curves. The earth connections should consist of metallic conductors connected to the lower conductors on the building, and should descend into the ground and extend as far as possible, preferably where the earth is damp.

2. The metallic parts of the building and masses of metal in and upon it, especially those in contact with the earth and offering large surfaces (such as pipes),

should be connected together as much as possible, and to the conductor also. Special receivers and conductors are rendered unnecessary if these metallic parts of the building comply with the requirements mentioned in paragraphs 1, 4, and 5. Both for perfecting the system and for decreasing cost, the question of utilizing the pipes as conductors should be considered when erecting new buildings, making use also as much as possible of all the metallic parts of the building for protective purposes.

3. The protection afforded by a conductor is the greater the more perfectly all the prominent portions of the building are protected by receivers, the larger the number of receivers and conductors, and the more extended the connections to earth. Generally speaking, damage by lightning is diminished if all the metallic parts of buildings of considerable extent are interconnected, especially if the highest parts are connected to earth, even if these connections are not made specially with a view to protection from lightning.

4. Interconnected conductors of iron should not have a section of less than 50 square millimeters, unconnected ones not less than 100 square millimeters. If of copper, half the section is sufficient; zinc must be one and a half, and lead three times the section for iron. Conductors must be securely fixed to resist strong winds.

5. The connections of and to the conductors must be made strong, be of good electrical contact, and with as large a surface as possible. Unwelded and unsoldered connections should have metallic surfaces of contact of not less than 10 square centimeters.

The lightning-conductor system should be repeatedly tested; and when alterations are made in the building, the necessity of alterations in the lightning-conductor system should be considered.

Baurat Findelsen, of Stuttgart, deduces from certain statistics as to strokes by lightning in Würtemberg that there is some doubt as to the efficacy of intercepting rods in attracting and protecting against lightning, and that there is no point in measuring the resistance of lightning conductors, since the high pressure of lightning would overcome even high degrees of resistance. It would be sufficient, he thinks, if all the protecting sheet metal on the roof ridge and elsewhere were connected with the gutters and rain-water pipes—if the chimney, which is so often struck, were protected by a rope (3 to 4 mm.) of galvanized iron wire, projecting to a height of one-half to one meter above the chimney, and joined as a conductor with the protecting metal, and if the water pipes were used as earth connections, they also having a strong wire rope running along them, which, at the lower end should be untwisted and carried in fan shape about half a meter down into the ground. Four such earth connections at the corners of the building to be protected would suffice. If yet further precautions are desired, galvanized sheet iron might be substituted for this. Lightning conductors of this type have proved their efficiency.









Sci 769.115

Bulletin No. 38—W. B. No. 435.

U. S. DEPARTMENT OF AGRICULTURE.

WEATHER BUREAU.



MISSISSIPPI RIVER LEVEES AND THEIR  
EFFECT ON RIVER STAGES DURING  
FLOOD PERIODS.

Prepared under direction of WILLIS L. MOORE, Chief U. S. Weather Bureau.

BY

SAMUEL C. EMERY,  
LOCAL FORECASTER.



WASHINGTON:  
WEATHER BUREAU.  
1910.



*Handwritten text, possibly a signature or date, is faintly visible below the stamp.*

## LETTER OF TRANSMITTAL.

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U. S. DEPARTMENT OF AGRICULTURE,  
WEATHER BUREAU,

*Washington, D. C., June 7, 1910.*

*The Honorable,  
The Secretary of Agriculture,  
Washington, D. C.*

SIR: I have the honor to transmit herewith a paper by Mr. Samuel C. Emery, Local Forecaster in charge of the local office of the Weather Bureau at Memphis, Tenn., on "Mississippi River Levees and their Effect on River Stages During Flood Periods."

I recommend the publication of this paper as a bulletin of the Weather Bureau.

Very respectfully, your obedient servant,

WILLIS L. MOORE,  
*Chief United States Weather Bureau.*

Approved.

JAMES WILSON,  
*Secretary of Agriculture.*



## MISSISSIPPI RIVER LEVEES AND THEIR EFFECT ON RIVER STAGES DURING FLOOD PERIODS.

The Mississippi River, following its winding course from near Lake Itasca, in northern Minnesota, to the Gulf of Mexico, is about 2,446<sup>1</sup> miles in length. The head waters of its tributaries extend from New York on the east to northern Montana on the west, and its drainage area is 1,242,600 square miles, about two-fifths of the total area of the United States. The river is navigable throughout from St. Paul, Minn., to its mouth, a distance of 1,954 miles. The head of navigation is Cass Lake<sup>2</sup> about 2,380 miles from its mouth, and the total navigable length of the entire system is 13,869<sup>3</sup> miles.

The lower Mississippi River, that portion extending southward from Cape Girardeau, Mo., to the Gulf, a distance of 1,128 miles, flows in a bed composed largely of sedimentary matter deposited by the river itself, and is typically a river with unstable bed, with rapidly caving banks, and shifting bottom. Except where the river strikes one of the bluffs that are found at long intervals south of Cairo, most of which are on the left bank, the banks range in height from about 25 to 40 feet above extreme low water. As the river in times of flood rises to 40 or 50 feet above the low-water line, the banks as well as the low lands lying back of them are consequently subject to overflow. The Mississippi River at all times contains a varying amount of material held in a state of suspension or rolled along the bottom by the motion of the water. When the water in the river becomes unusually agitated, as at flood time, and bank erosion is going on rapidly, the amount of sediment is greatly increased. At an active rising stage the material carried past a given point is said to be equal to 1,000 tons a minute. Now when the amount of water in the river is too great to be contained within its natural banks it flows out over the adjacent lands, where its motion being arrested, the sediment is deposited. Naturally the greater portion of the sediment is dropped near the river bank and the finer and lighter particles are carried farther inland. Thus it comes that the lands nearest the river, by receiving this annual deposit, are slowly built up until they have become considerably higher than those farther toward the interior. This is especially noticeable in the St. Francis and Yazoo basins, where the slope and consequently the drainage, is away from the river instead of toward it as is the case with most rivers.

From St. Louis to the Gulf the river drops 380 feet in a series of alternately reversed bends. In the bends the current impinges on the con-

<sup>1</sup> Annual Report, Chief of Engineers, 1909, p. 2677.

<sup>2</sup> Annual Report, Chief of Engineers, 1909, p. 564.

<sup>3</sup> Preliminary Report of Inland Waterways Commission, 1908, p. 35.



cave bank, causing a deepening of the water along the shore and, in most cases, rapid caving and erosion of the bank. At the foot of each bend the main flow crosses to the other side, impinging on the concave bank on that side, and so back and forth, the place in the channel where this takes place being called a "crossing." In these crossings the current slackens and there results a local deposit of the rolling or suspended material moving with the water which deposit forms a "bar." Thus it happens that there is a shoaling of the river with a bar of some dimensions between every two bends in the river as well as at any point of a straight reach where the river is unusually wide. Some of the bars are not built up sufficiently to obstruct navigation or deflect the current noticeably, while others spread over large areas and rise to within a few feet of the water surface. The bottom of the river, if exposed to view, would show a succession of great sand hills and intervening depressions. It is the tops of the sand hills that form the bars obstructing navigation, and in order to provide navigable depths during periods of low water, the Government maintains a fleet of 10 or 12 powerful hydraulic dredges that cut channels through the bars, discharging the dredged material outside of the channel through a pipe line. These dredges operate between St. Louis and Vicksburg during the low-water months and usually maintain navigable channels throughout the year, except when the river is closed by ice.

The greatest and most fertile portion of the alluvial lands along the Mississippi River between Cape Girardeau and the Gulf being below the level of the flood, the first object of the planter has always been to secure himself against inundation in times of high water. To obtain this immunity the only practical method that has so far suggested itself is to raise the banks high enough to hold all the water and keep the river within certain permanent and prescribed limits. Thus the system of artificial embankments or "levees" as the French called them, came into use at a very early day, and the same system, though greatly improved as regards construction, prevails at the present time. The use of the levee as the sole method of restraining the waters of the Mississippi for the protection of the alluvial lands against the ravages of floods has been in practise since the year 1718, when the first settlement at New Orleans being greatly harassed by high water, began the construction of a levee about 3 feet in height in front of the town. By 1752 levees had been built along the river front 20 miles below and 30 miles above New Orleans. These levees were built by the planters themselves, each building a levee the length of his river front. In 1743 an ordinance was promulgated requiring the inhabitants to complete their levees by the 1st of January, 1744, under penalty of the forfeiture of their lands to the crown. Work progressed slowly up the river during the French and Spanish occupation and even after the Louisiana Purchase in 1803. In 1812 the levee extended a length of 155 miles on the east side of the

river and about 185 miles on the west side. The total length of the levees in 1812 was therefore 340 miles, and it is said that the amount expended in this work was between five and six million dollars. By the year 1828 the line of levees was continuous from Red River Landing to 65 miles below New Orleans, a distance of 260 miles.<sup>4</sup> With the view of aiding the several States bordering the river in the construction of protection levees, the Federal Government in 1850 issued by grant certain swamp lands, which were to be sold by the States and the funds obtained thereby to be applied to levee work and drainage. Though many of these lands were of no commercial value at the time and could not be sold, a considerable sum of money was realized, and for a time levee construction went on at a rapid rate. The levees, however, were of low grade and inferior construction, and consequently proved of little avail when tested by the great flood of 1858, which carried away the greater portion of the embankments north of the mouth of Red River.

At the outbreak of the civil war the levees in the Yazoo district were fairly continuous, but of too low grade to offer much protection, except during moderately high water, and by the time hostilities ceased there was little left to show that levees had ever existed.

The great flood of 1882, which inundated the entire delta, directed forcible attention to the necessity for united and organized effort toward controlling the flood waters. For the purpose of closing the many crevasses made by the flood of that year, an allotment of \$1,300,000 was made from the funds appropriated by Congress in the River and Harbor Bill of that year for the improvement of the Mississippi River, which was the first allotment ever made by the Federal Government for levee purposes. Following this, small allotments were made for certain repairs in the levees made necessary by the succession of floods in 1883 and 1884. These allotments for repair of levees and subsequent allotments for construction and maintenance of levees were made by the Government for the purpose of improving the navigation of the stream, acting in accordance with the theory that the construction of levees would restrain the water in times of flood within a narrow space and that the additional force given by the weight of the water, together with the increased rate of flow, would tend to scour the channel and thus prevent the formation of sand bars by the deposit of sediment. This theory which led to the adoption of the plan for concentration of the waters of the river into one channel of an approximately uniform width, had been successfully applied in the opening and keeping open a deep channel through the South Pass of the Mississippi River from the head of the passes to the Gulf, and the success attained in that undertaking led to the belief that the same theory if applied to the entire river would deepen the channel.

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<sup>4</sup> Riparian lands of the Mississippi River, (Tompkins), p. 140.

In support of his claim that the so-called "jetty system" could be applied to the river from the Gulf to the head waters, Captain Eads said :

There can be no doubt of the entire feasibility of so correcting the Mississippi River from Cairo to the Gulf that a channel depth of 20 feet during low-water season can be permanently secured throughout its entire course, and the alluvial lands on each side of its waters can be made absolutely safe from overflow.

The first step taken was the creation of a permanent commission to be known as the Mississippi River Commission, and the act creating this commission became a law in June, 1879. This commission submitted a report in the year 1880, defining plans to be followed in the permanent improvement of the lower Mississippi River, the recommendations of which report were adopted by Congress as the project for the systematic improvement of the river

The Valley of the Mississippi is divided into a number of subordinate basins, each in a measure independent of the others, so that the task of protection against overflow is much simplified by reason of the fact that it did not necessarily require a vast and simultaneous organized effort or continuous levee system, but was one that could be undertaken in detail. Above the mouth of Red River there are four great basins, drained respectively by the St. Francis, the Yazoo, the Tensas Bayou, and Atchafalaya and their tributaries. All of these are now leveed, although the nearest approximation to a complete system has been made on the Yazoo front. The St. Francis Basin is a great oval plain with the Mississippi River from Cape Girardeau, Mo., forming its eastern boundary and a ridge of low hills, known in different places along the line as Hickory Ridge, Bloomfield Ridge, and Crowleys Ridge, forming its western one. Its greatest length is 218 miles, and it has an average width of 25 miles. From Commerce, Mo., to the lower end of the basin at Helena, Ark., the right bank is low, except at New Madrid, Mo. The upper portion of the St. Francis Basin is mostly hilly, while the lower and much larger portion is low and swampy with numerous lakes and bayous. This part of the basin slopes away from the river, and it also has a southern slope of 0.7 foot per mile. The basin is drained by the St. Francis River, which flows southward near the foot of Crowleys Ridge, and meets the Mississippi about 9 miles above Helena.

The Yazoo Basin is also an oval plain, and, like the St. Francis, slopes away from the Mississippi, a fortunate circumstance in connection with the construction of protection levees, as there are no streams emptying into the Mississippi for which openings were necessary. The eastern boundary of this great basin is a line of low hills along the base of which flows its principal drainage stream, known in its upper reach as the Coldwater River and toward its confluence with the Mississippi as the Yazoo. This stream is navigable for about 240 miles from its mouth.

The northern limit of the basin is near the Tennessee-Mississippi line. Here it is quite narrow, but farther south it widens out to a width of about 70 miles and then narrows again near the lower end at the mouth of the Yazoo. Its greatest length is 180 miles, and with the exception of a low ridge from 2 to 6 miles in width, an extension of Crowleys Ridge in Arkansas, which crosses the bottoms, the whole region is liable to overflow during times when the Mississippi is in flood.

The Tensas Basin extends from near the southern border of the St. Francis Basin to the mouth of Red River, its eastern boundary being the Mississippi River. The banks and the land generally are low and similar in character to those of the St. Francis and Yazoo basins, except that the Arkansas and White rivers find an outlet into the Mississippi, a fact which seriously interfered with levee construction.

The swamps in this basin are drained by Bayou Tensas, which unites with the Ouachita and Little rivers to form the Black, the most important tributary of the Red. The work of permanently closing this basin was commenced in 1888 and most of it was done after 1890. In 1897 the basin had been inclosed by a levee of an average height of 12 feet, but even then the flood overtopped the levee in many places, and several crevasses occurred. At the present time the levee in front of the Tensas Basin extends in an unbroken line from the high ground near Helena to the mouth of the Arkansas River and from near the mouth of the Arkansas to about 8 miles above the mouth of Red River.

Between Cape Girardeau, Mo., and Vicksburg there are five or six levee districts, organized under the laws of the various States, each with a separate board and corps of engineers, having control over the location and construction of levees along the front of the district, settling questions of rights of way, etc. The Federal Government, acting through the Mississippi River Commission, cooperates with the local levee authorities to some extent by allotting for levee work a portion of the funds appropriated by Congress for the general improvement of the river, which funds are expended in constructing on rights of way donated by the local levee boards, new levees where necessary to preserve the continuity of the line, in raising and enlarging old levees to a standard grade, and in assisting the local authorities in preserving the levees during flood periods.

The upper St. Francis levee district extends from the high lands at Commerce, Mo., to New Madrid, Mo., a distance of 85 miles. The levee is now built from about 20 miles above Cairo to about opposite Hickman, Ky., and though a line from that point to New Madrid has been proposed, the work is still held in abeyance on account of the difficulty in settling the question of drainage. In that section of the district several small rivers and bayous draining that portion of the State empty into the Mississippi and, until a means is provided for taking care of the surface water, this stretch of about 30 miles will remain

open. On the left bank of the river a line of levees now runs from Hickman, Ky., to the foot of Donaldsons Point, which is about opposite Point Pleasant, Mo., the northern end of the lower St. Francis levee system. The purpose of this levee is to restrain the overflow water from passing into Reelfoot Bottom and flooding Lake County, Tenn., and other sections in that vicinity.

The lower St. Francis levee district extends from Point Pleasant, Mo., to Helena, Ark. Formerly when the Mississippi between Cairo and Memphis reached a stage of 25 or 30 feet, the water would spill over the low banks and back up the numerous bayous until the swamps and low places were filled. Then as the river rose still higher, the surplus water would flow uninterruptedly over the land to the westward and enter the St. Francis River through which it found its way to the main stream at Helena. The purpose then of the St. Francis levee is to compel the flood waters in the Mississippi River to follow their natural channel instead of flowing out over the land. Levee construction in the lower St. Francis district began soon after 1850, and by 1858 a somewhat broken line of embankments extended from the high lands below New Madrid, Mo., to near the lower end of the basin. These, however, as before stated, were of little avail against floods and most of them were soon destroyed. Nothing further was done toward an organized movement to close the basin until 1893, when the first St. Francis Levee Board was formed, and the Government began to make yearly allotments for levee work. When the great flood of 1897 occurred the St. Francis levee only extended as far south as Pecan Point, a distance by river of about 125 miles. This line was made up principally of the old State levee above referred to, which had been enlarged and strengthened, but when put to test by the flood was found too small and upon the whole quite inadequate to effect the object intended. While this levee in a measure resisted the ravages of the flood in some places, there were 23 serious breaks in 1897, mostly in the lower portion of the line, and as a result the country received very little protection. Six years later, in 1903, this line of levee had been extended southward as far as Cat Island, below Memphis, a total length of 173 miles. The whole line had been practically rebuilt when the flood of 1903 occurred and in that year there were only two breaks, notwithstanding that the water was much higher than in 1897.

The present length of the lower St. Francis levee line is 202.5 miles, which added to the upper St. Francis line, comprising 47.5 miles, gives a total of 250 miles of levee on the right bank of the river above Helena. Below Helena on the right bank of the river, the White River district has 74 miles, upper Tensas 190.6 miles, lower Tensas 153 miles, a total of 417.6 miles, which added to the 250 miles in the St. Francis system gives a total of 667.6 miles of levee on the right bank above the mouth of Red River.



The St. Francis levee has an average height of 16 feet, with a base 104 feet and a crown 8 feet in width, topped by a curved section with a 3-foot crown. The levee of course varies in dimensions according to the level of the location upon which it is built, but it is believed to be sufficient to hold a volume of water equal to that of 1882. The work already done in this district alone has cost the people of the St. Francis Basin \$2,500,000, in addition to about \$2,000,000 allotted by the Federal Government. The work yet to be done in order to bring the St. Francis levee system to the ideal proportions will probably increase the total expenditure to near \$7,000,000. The great value of this levee to the country will be the reclaiming of 2,240,000 acres of the richest and most productive soil in the world.

The Yazoo Levee Board was organized in 1884. At that date the levees were insignificant, both in height and other dimensions and of very inferior construction as compared to present levees. They had been long neglected and in some places there was little to distinguish them from the natural ground. They could therefore afford little or no protection against a flood. The upper Yazoo levee district covers a distance of 124 miles and extends from the northern line of the State of Mississippi, near Horn Lake, to the southern boundary line of Bolivar County. The lower Yazoo district extends from the Bolivar County line to near the mouth of Yazoo River, a distance by river of about 230 miles. The length of this line of levees is 188 miles, making in all 312 miles of levee in the State of Mississippi. These levees are practically complete and are considered sufficient to withstand the highest water.

In 1882 the lower Yazoo levee line was very irregular in grade, with an average height of only about 7 feet and broken by extensive gaps. In that year or immediately following the great floods of 1882 and 1883, the real work of constructing a levee on something approaching modern lines began, and the work progressed so well that in 1884 there was but one crevasse in the entire line. After this no break occurred in the lower Yazoo district until 1890, when there were six, and again in 1891 when one break occurred. In 1897 occurred the greatest overflow ever experienced in the lower valley; the levee in this district broke in five places, and one very serious crevasse occurred in the upper district, making six in all. In 1903 one break occurred in the lower district, but since that year the levees have withstood all floods.

On July 1, 1908, there were 1,486 miles of levee along the river south of Cape Girardeau, Mo., not including those on the tributary streams. Since that time some extensions have been made and many miles of new levee constructed to replace those that were located too near the river, or upon unstable foundations. One of the many serious problems confronting the levee builder is that of caving banks. These encroachments of the river, which most often take place in the bends, frequently bring about changes in the course of the river and annually destroy many

miles of expensive levees which must be replaced by new ones built farther back from the river. In certain of the bends of the river as many as five lines of levee have been built in the past thirty years and as long as these conditions exist, a strictly permanent levee system is impossible. Again, the ever-increasing elevation of the flood planes, due to additional constrictions of the flood volume by the extension of new lines of levees, renders the establishment of permanent levee grades extremely difficult, if not impossible, until they are brought to an actual test under the newly-developed conditions. The flood of 1897 found the river in the Yazoo district leveed on both sides for the first time in history, and the effect of this was a filling of the depressions, the establishment of a new flood plane in accordance with the changed conditions, and a disturbance of gage relations at all points above Helena. In this way, new grades that have been established at various points in the St. Francis system, in accordance with the changed conditions due to the presence of levees on the left bank of the river, have raised the flood plane above the original estimates, and as a result a vast amount of enlargement work has been required. These enlargements and the building of new loops around badly-constructed or improperly-located levees constitute the principal work at the present time.

The total amount expended by the Federal Government on levee work below Cairo to July, 1908, was something over \$23,000,000, and, while the amount expended by the different States is not known, it is supposed to have been in the neighborhood of \$30,000,000. The area protected by these levee systems is approximately 27,000 square miles or about 17,300,000 acres.

#### EFFECT OF LEVEES ON FLOOD STAGES.

In former times the effects of a rise in the river upon the swamp lands began to appear when the rising water attained the level of the bed of the connecting bayous, that is, when the surface of the river was still 10 or 15 feet below the top of the natural banks. The first effect was to stop the discharge of these bayous and to accumulate rainwater in the swamps. As the Mississippi rose to still higher levels a considerable volume of water was poured into the bottoms through the numerous bayous and other outlet streams, and as a result the swamps and low places were often well filled before the river even reached a bank-full stage.

Since the levees, as now constructed, close these bayous and exclude the Mississippi water from the swamps, their effect on the river become apparent to some small extent with stages as low as 25 feet, becoming more and more pronounced as higher levels are reached. The ground usually being higher near the edge of the bank than at the base of the levee, a flood which only partially covers the ground in the vicinity of the bank, often puts several feet of water against a levee that has been



built some distance back from the river, while one built on the immediate bank is entirely free from water.

It is probable that the levees constructed previous to 1871 from Cape Girardeau to Vicksburg had the effect of increasing the height of the flood plane in certain reaches of the river, but, owing to the lack of continuity in the line of levees and the absence of comparable stage data, it is not possible to even approximate the changes in the river regimen until a much later date.

In 1871 river gages were established at several places along the river and daily observations of the height of the river became a part of the duties of the Weather Bureau observers at all river stations. This was the beginning of a systematic daily survey of the river fluctuations that has continued without change or interruption to the present time. The Mississippi River Commission was created in 1879, and soon thereafter the course of the Mississippi was accurately surveyed and its slope determined by precise levels. Additional river gages were also established at that time, so that since 1880 the daily stages have been recorded at intervals of about 50 miles or less along the entire course to New Orleans.

The zero point on the Mississippi River gages usually represents the lowest level the surface of the water had reached at the time the gage was established, but in many instances the water has since gone below this mark. The elevations of gage zeros are referred to the mean Gulf level at Biloxi, Miss. That is, the elevation of the zero of the gage at Cairo is 270.9 feet above mean Gulf level, Memphis, 184.1 feet, Helena, 142.1 feet, Greenville, 88.5 feet, Vicksburg, 46.2 feet, Natchez, 17.1 feet. Thus the zero elevations of the various gages give approximately the low-water plane of the river. An approximate relationship exists between the gage readings on the Mississippi when normal stages prevail, and if the natural banks were sufficient to hold all the water that passes Cairo this relationship would be fairly constant, except when disturbed by heavy discharges from tributary streams. But, through the overflowing of banks and the consequent loss of water to the swamps, the crest of a rise loses its identity and the relation between the gages is seriously disturbed. The occurrence of a crevasse at any point in the line of levees has the same effect on all gages located between the point of the break and the foot of the basin.

Since 1882 the conditions affecting the flood regimen in this reach of the river have materially changed by the extension and enlargement of the levees, and during the twenty years ending with the year 1903, they have undergone an annual change so that rules established in one flood year could not be successfully applied to the one following, no two being exactly alike. However, with stages of 30 feet or under at Cairo the relation between the gages is probably very near what it was in 1871; in fact, the records show very little change.

Levees have no marked effect on river stages, except when the river is out of its banks or rises sufficiently high to cause a considerable amount of water to back up the tributary streams where such exist. In this reach of the river (Memphis) there is very little loss of water unless the river reaches a stage of about 25 feet at Memphis.

As all great floods emanate north of Cairo the gage at that place is accepted as an index to what will follow at points below.

The difference between Cairo and Memphis, with Cairo reading 20 feet or less, is from 5 to 7 feet and for stages up to 30 feet at Cairo the difference is approximately 7 feet, Cairo reading the higher. These were the gage relations in 1872 and they are practically unchanged at the present time. Previous to 1896 when the water during flood periods was unrestrained by artificial embankments, the difference between Cairo and Memphis increased in proportion to the height of the flood wave, while under the changed conditions south of Cairo, the tendency during extreme high water is for the two gages to come closer together. Formerly a 46-foot stage at Cairo gave Memphis 35 feet, which was the maximum at the latter place up to 1897, when the levees first began to show their effect. The highest stage on record at Cairo is 52.3 feet, which occurred in 1883, and the resultant stage at Memphis was 35 feet, or the same as is now shown by a 46-foot stage. This indicates that there was a loss due to overflow water passing into the bottom lands of about 7 feet. The difference between Cairo and Memphis in 1882, 1883, and 1884, when the stage at Cairo reached the extreme height of 52 feet, was 17.5 feet. In 1897, with an imperfect levee fronting only about one-third of the St. Francis Basin, the difference was reduced 3 feet. In 1903, with a still incomplete levee and two serious breaks a few miles above Memphis, the difference was only 10.6 feet, a reduction since 1897 of about 4 feet, and since 1884 of about 7 feet. In 1907, by reason of the further extension and enlargement of the St. Francis system of levees, a further increase in the flood level at Memphis is shown. In that year the difference between the Cairo and Memphis gages was exactly 10 feet, showing that the flood plane at Memphis had been raised 7.6 feet since 1884, and that this increase was brought about by confining the water to narrower limits through the extension of the Arkansas levee along the right bank of the stream. It should be borne in mind that notwithstanding the abnormal stages below Cairo in 1903 and 1907, the actual volume of water coming into the valley was much less than in either 1882 or 1884 and decidedly less than in 1897. Not only was the stage at Cairo 1 foot below the record for the years named, but the wave was much shorter. At Cairo in 1882 the water was above a 40-foot stage on 81 days, above 45 feet on 56 days, and above 50 feet on 9 days. In 1907 it was above these stages on 34, 16, and 4 days, respectively.

Since 1907 a line of levees has been constructed in Scott County, Mo., from the high ground at Commerce, Mo., to the west end of Big Lake,

about 15 miles west of Cairo, where it joins the Mississippi County levee and forms a continuous line to below Island No. 5. The closing of this reach of 15 miles will, in times of overflow, prevent the water from flowing out over Scott County, Mo., to the tributaries of the White and the St. Francis rivers, by which they were formerly carried southward to join the main stream at Helena and below. Another factor having a material effect on the gages at New Madrid and Memphis is the new line of levees on the left bank running from Hickman, Ky., southward to near Tiptonville, Tenn., but as this levee has not yet been built to the standard grade, its effect during extreme high water is uncertain. As the highest water that has occurred since 1907 is over 5 feet below the extreme stage, it is difficult if not impossible to accurately determine the final effect of these recent levee extensions on the river below Cairo, but at the highest stage in 1909, 47.3 feet at Cairo, an increase in the flood plane is noted at both New Madrid and Memphis. The increase at New Madrid certainly amounts to 2 feet, while at Memphis it is probably somewhat less. It is reasonably certain, however, that a flood equal to those of 1883 or 1884 would give Memphis at least 43, and possibly 44 feet, provided there were no breaks in any of the levees. Table 1 gives the maximum stages at different points along the river during the three great floods that have occurred since 1882, and also during the year 1909, and shows the changes in the gage relations to the present time; also the expectations regarding future floods based on the water of 1882:

TABLE 1.

Stations.	1882.		1897.		1903.		1907.		1909.		Expectation based on 1882.
Cairo.....	51.8		51.6		50.6		50.4		47.3		
New Madrid.....	41.5	-10.3	40.3	-11.3	39.5	-11.1	39.3	-11.1	38.6	- 8.7	44.0
Fulton.....	36.7	-15.1	37.5	-14.1	40.2	-10.4	38.4	-12.0	35.5	-11.8	41.0
Memphis.....	35.2	-16.6	37.1	-14.5	40.1	-10.5	40.3	-10.1	38.6	- 8.7	43.5
Helena.....	47.2	- 4.6	51.8	+ 0.2	51.0	+ 0.4	50.4	+ 0.0	47.7	+ 0.4	52.0
Arkansas City...	47.0	- 4.8	51.9	+ 0.3	53.0	+ 2.4	52.1	+ 1.7	50.1	+ 2.8	55.0
Greenville.....	41.7	-10.1	46.8	- 4.8	49.1	- 1.5	47.3	- 3.1	44.8	- 2.5	51.0
Lake Providence	38.3	-13.5	44.5	- 7.1	46.5	- 4.1	46.3	- 4.1	44.4	- 2.9	48.0

All changes are computed from the maximum stages at Cairo.

The estimates here made are based on data taken from the early spring rises only. At such times the ground is well saturated and the swamps and tributary streams more or less full of water, and as a result a flood wave coming into the valley produces its maximum effect. Later in the spring or during the early summer months, with a deficient moisture supply in the ground, and with the streams low, a given stage at Cairo will give lower resultant stages at all points below. Again, the crest stage is affected to a considerable extent by the condition of the White and Arkansas rivers. This is particularly noticeable at Helena and Arkansas City. With those rivers in flood, or when the

lower Mississippi is abnormally high, the slope is somewhat decreased and consequently the run-off is checked to an extent sufficient to cause the Helena gage to show a higher stage with reference to Cairo than would be the case if the lower rivers were low and the slope normal. Under the latter condition it is possible for a 45-foot stage at Cairo to give 35 feet at Memphis and 44 feet at Helena, and corresponding stages at points below. However, under favorable flood conditions, the Memphis gage will show from 8.5 feet to 9.5 feet less than Cairo on stages exceeding 40 feet at the latter station. The difference between Cairo and Helena for stages under 35 feet is about 1.5 feet, that is Helena will be that much below Cairo, while the difference at Memphis is from 7.5 to 8 feet.

#### EFFECT OF LEVEES ON THE RIVER SOUTH OF MEMPHIS.

Helena, Ark., being located at the lower end of the St. Francis Basin, the gage at that place was formerly affected to a considerable extent by the return flow of the waters that had escaped from the main stream between Cairo and Memphis. It has been estimated that this return flow, which usually occurred about the time the flood crest reached Helena, had the effect of raising the stage at that place about 3 feet. That it prolonged the flood at Helena there is no room for doubt, as will be seen in another portion of this report. Mr. H. N. Pharr, Chief Engineer of the St. Francis Levee Board states in this connection as follows:

The return flow from the St. Francis Basin at Helena has the effect of raising the water on that gage at least 3 feet above what it would do if the basin had been closed. An idea of the quantity of support given the flood in the lower river may be had when it is stated that the area of the St. Francis Basin is about 5,000 square miles and the average depth is about 8 feet. Supposing the basin to be filled, as sometimes was the case, this water would equal a stream one mile wide, 1,000 miles long, and 40 feet deep. Flowing at the rate of 1,000,000 cubic feet per second, or an average velocity of 4.5 feet per second, it would take 14.5 days to run out. This is close to what, in fact, occurs.

The idea of building the St. Francis levee until those below were perfected, was strongly opposed by property owners along the lower river, the objection being based on the supposition that closing the basin would raise the flood height at Helena and from there southward to the Gulf. Engineers, at least many of them, held to the opposite opinion, and some went so far as to say it would lower the flood at Helena and possibly at points below.

Colonel Suter of the United States Engineer Corps gave it as his opinion that—

In a general way it has been shown that the large increase in the flood height has been mainly confined to intermediate points along the great swamp basins. At the lower end of these basins the change has been slight, as for instance, Vicksburg. The only feature of the uncertainty which now remains is the effect of leveeing the St.

Francis Basin. That will increase the flood height at Memphis and all points above seems certain, but so far as concerns the river below Helena there is much to be said. All the water which now reaches the main stream above the junction with the White River now passes Helena between levees, and hence has produced its maximum effect.

During the great floods of 1882, 1883, and 1884, the maximum stages at Helena and their relations to the Cairo gage were substantially the same, that is to say, Helena had 47 feet against 52 at Cairo, a difference of 5 feet. At that time there were no levees on the Arkansas side of the river, and those on the left bank were not sufficient to hold the water at flood stage. By 1886, however, the Mississippi state levee had been enlarged; the crevasses that were made during the great floods that occurred after 1882 were all closed, and, although the river reached a stage of 48.1 feet, no break occurred. This was 1 foot higher than ever before known at Helena, notwithstanding the fact that Cairo was 1 foot below its maximum. This would indicate that the levee was responsible for an increase in the flood height of 2 feet.

The next extreme high water occurred in 1897, and at that time there was a good, strong levee on both sides of the river in the vicinity of Helena, but otherwise the conditions were about the same as when the floods above mentioned occurred. The maximum stage at Helena was 51.8 feet, or nearly 5 feet above the previous record, while Cairo was still a fraction of a foot below the extreme flood stage. A higher maximum would probably have been shown had it not been for the great Flower Lake crevasse, which occurred on the opposite side of the river, a few miles above Helena on April 3, and diverted an immense body of water to the swamps of Mississippi. At the time the crevasse occurred the river was rising steadily at the rate of three or four-tenths of a foot daily, so it is reasonable to suppose that, if the levee had held, Helena would have experienced a stage exceeding 52 feet. At this time the St. Francis Basin was only leveed from Point Pleasant, Mo., to Pecan Point, Ark., and even that offered but little resistance to the flood.

In 1903 the St. Francis levee extended only to Cat Island, a few miles below Memphis, and from there to the foot of the basin there was no levee protection whatever. In addition to this there were two serious crevasses a few miles above Memphis, so that the lower portion of the basin was about as deeply flooded as in former years when there were no levees at all. This being the case the gage relation between Cairo and Helena that obtained in 1897, was not disturbed, both recording practically the same stage.

The first real test regarding the effect at Helena came in 1903. The St. Francis levee system was complete from the high ground in Missouri to the mouth of the St. Francis River and the whole line, both above and below Helena, was intact. Referring to Table 1 it is seen that Helena still follows Cairo very closely, and the two gages have the same relation to each other as in 1897 and 1903. Thus the contention that the St.

Francis levee would not raise the flood level at Helena is to some extent verified. The fact remains, however, that there is a fairly permanent ratio of unity between Cairo and Helena at an overflow stage, and the contention of some eminent engineers that the extreme maximum at Helena would not exceed 49 feet does not appear to be well founded. That the St. Francis levee did not raise the flood level at Helena is due to the fact that the return flow from the basin has been eliminated and this offsets whatever effect the restraint offered by the levee may have had.

While the complete closing of the St. Francis Basin has had the effect of giving increased stages at all intermediate points it is seen by Table 2 that it has also had the effect of materially shortening the duration of the floods at Memphis and Helena as well as at some points below:

TABLE 2.—*Number of days above flood stage.*

Year.	Cairo.	Memphis.		Helena.		Arkansas City.	Greenville.	Lake Providence.	Vicksburg.
	45 feet.	33 feet.	35 feet.	42 feet.	45 feet.	42 feet.	42 feet.	42 feet.	45 feet.
1882.....	56	65	6	79	48	108	0	0	39
1890.....	43	41	35	28	32	112	40	0	95
1897.....	47	55	45	66	48	72	45	42	70
1903.....	20	43	23	65	29	81	39	27	60
1907.....	16	30	16	33	19	59	31	29	33

At Memphis the river was above flood stage (33 feet) on 55 consecutive days in 1897, 43 days in 1903, and 30 days in 1907. At Helena it was above flood stage (42 feet) on 66 days in 1897, 65 days in 1903, and 33 days in 1907. In 1897 Cairo was above flood stage (45 feet) on 47 days, and above 50 feet on 15 days. In 1907 it was above 45 feet on 16 days, and above 50 feet on 4 days. It is true the volume of water in 1907 was not equal to that of 1897, but the difference in volume is not sufficient to account for the great decrease in the length of the flood period at Helena, that is, from 66 to 33 days. At Memphis the effect of the river as regards the run-off is not as noticeable as at Helena, but it is believed the flood period has been shortened at the former place, as shown by the rapidity of the fall in 1904 and 1907, as compared with previous floods. In 1907 it was not until 43 days after the arrival of the crest that the water fell below flood stage, while in 1904 it took only 10 days, and in 1907 only 9 days.

As floods in the lower Mississippi River usually occur during the planting season, the importance of hastening the withdrawal of the water from the land can not be overestimated. A difference of a few days may sometimes determine the fate of a crop. There are large tracts of rich tillable land lying unprotected along both banks of the river, as well as numerous island plantations that are more or less flooded each year. These overflows are expected, and, as a rule, are of great benefit to the



soil, as they leave a rich deposit on the land. The levees have caused these lands to be more extensively and more deeply flooded and in some individual cases have worked a distinct hardship to the people occupying them. At the same time, if the period of inundation is materially shortened by confining the river to its natural limits, this hardship is greatly mitigated, and, on the whole, the levees may prove a benefit even to the lands that have no protecting levee.

Below Helena the gage readings show an increase in flood planes from 1882 up to the present time. These changes are very pronounced at all intermediate points along the Yazoo and upper Tensas fronts, and the least noticeable at Vicksburg, which is located at the bottom of the basin. The greatest increases in the flood plane are seen at Lake Providence, La., Greenville, Miss., and Arkansas City, Ark., respectively. In 1883 Greenville was 11.8 feet below the Cairo gage, but in 1903 the difference had been reduced to 1.6 feet, an increase in the flood plane of 10.2 feet. At Lake Providence the effect of levee construction on the flood waters is even more pronounced, the increase at that place amounting to 12 feet. At Arkansas City, previous to 1897, the flood crest was usually about 5 feet below the Cairo reading, but in 1903 it was 2.2 feet above, an increase of about 7 feet since 1890.

The abnormal stage at Greenville in 1903 and the remarkable change in the gage relation between Greenville and Arkansas City has been extensively discussed by engineers and others, and various theories have been advanced as to the cause. When the levees were small they were built so as to follow very closely around the bends and points because the highest ground was usually found close to the river bank, and on many of the points the bank was so high that up to 1882 levees were unnecessary. Then the points were practically leveed in. This had the effect of causing the high-water channel to conform closely to the low-water channel. As the different basins on each side of the river began to be leveed and closed up, the high-water level rose higher and higher, making it necessary to increase the height of the levee. As this work is very expensive and the value of the land on the points is not always in proportion to the cost of maintaining a high grade levee, it was often found expedient to shorten the length of the levee line by building new levees across the necks and throwing out the long lines around the points. This was done in that crooked reach of the river extending from Catfish Point, which is about 10 miles by river above Arkansas City, to Leland, just below Greenville. The distance along the channel of the river is about 48 miles, but in a direct line it is only 10 or 12 miles. The old levee following closely around the bends was about 53 miles in length. This was replaced by one running in a more direct line and disregarding the bends, so that a saving was made of about 42 miles of levee. The effect of throwing out the old levees around the bends is to give the flood water free sweep across the points instead of following



around the channel of the river as formerly, the same as though a series of cut-offs had been made in the bends above Greenville, thereby giving a greater slope to the water and consequently a greater velocity.

The writer believes that the abnormal height at Greenville in 1903 was due in part to the fact that the levees on each side of the river converge a few miles below Greenville, so that the distance between them is only about  $1\frac{1}{2}$  miles. This holds the water back and produces an effect similar to that which would be caused by a dam. At Arkansas City the distance between the Mississippi and Arkansas levees is 5 or 6 miles, and below the gage the distance ranges from 10 to 15 miles. It is probable that the increased slope and consequent increased velocity given the overflow water in passing across the points, as above explained, throws a larger volume of water into the narrow space between the converged levees below Greenville than would be possible if the water had followed the natural channel of the river. The average difference in slope between Arkansas City and Greenville, comparing maximum gage readings for the years 1884, 1887, 1891, and 1898, is 5.32 feet. At the highest stage reached in 1903 the difference was only 3.9 feet, showing an abnormal rise at Greenville of 1.4 feet.

TABLE 3.—*Extreme stages during four recent floods in the Mississippi River compared to 1882.*

	1882.	1897.		1903.		1904.		1907.	
Cairo .....	51.8	51.6	−0.2	50.6	−1.2	49.1	−2.7	50.4	−1.4
New Madrid.....	41.5	40.3	−1.2	39.5	−2.0	37.5	−4.0	39.3	−2.2
Fulton.....	36.7	37.5	+0.8	40.2	+3.5	37.4	+0.7	38.4	+1.7
Memphis.....	35.2	37.1	+1.9	40.1	+4.9	39.0	+3.8	40.3	+5.1
Mhoons.....	39.8	41.6	+1.8	41.8	+2.0	40.3	+0.5	42.2	+2.4
Helena .....	47.2	51.8	+4.6	51.0	+3.8	47.7	+0.5	50.4	+3.2
White River.....	48.4	52.4	+4.0	53.7	+5.3	49.5	+1.1	51.9	+3.5
Arkansas City.....	47.0	51.9	+4.9	53.0	+6.0	49.0	+2.0	52.1	+5.1
Greenville.....	41.7	46.8	+5.1	49.1	+7.4	43.5	+1.8	47.3	+5.6
Lake Providence.....	38.3	44.5	+6.2	46.5	+8.2	42.5	+4.2	46.3	+8.0
Vicksburg .....	48.8	52.3	+3.5	51.8	+3.0	46.9	−1.9	49.7	+0.9
Natchez.....	47.8	49.8	+2.0	50.4	+2.6	45.6	−2.2	48.9	+1.1

TABLE 4.—Annual maximum river stages.

Year.	Calto.	Memphis.	Helena.	Arkansas City.	Greenville.	Lake Providence.	Vicksburg.
1872.	39.2 Apr.	31.5 Apr.	39.0 Apr.			35.2 May	39.5 May
1873.	41.6 Feb.	32.5 Mar.	40.0 Mar.			36.1 May	40.6 May
1874.	47.4 Apr.	34.0 May	45.8 May			37.4 Mar.	45.7 May
1875.	45.1 Aug.	33.0 Aug.	42.4 Apr.			37.3 Apr.	43.0 Apr.
1876.	46.4 Apr.	34.1 Apr.	44.8 Apr.			38.0 Apr.	44.9 May
1877.	40.5 Apr.	32.0 Apr.	41.8 Apr.			35.8 May	41.6 May
1878.	37.0 Apr.	29.1 May	38.8 May			35.8 Mar.	41.0 Mar.
1879.	36.5 Dec.	28.1 Jan.	37.2 Jan.			36.0 Feb.	39.4 Feb.
1880.	44.6 Mar.	33.4 Mar.	43.8 Mar.	21 Mar.		38.0 Apr.	43.2 Apr.
1881.	45.8 Apr.	33.3 Apr.	43.7 Mar.	17 May		36.2 Mar.	41.8 Mar.
1882.	51.8 Feb.	35.2 Mar.	47.2 Mar.	28 Feb.	27 Feb.	38.3 Mar.	48.8 Mar.
1883.	53.3 Feb.	34.8 Mar.	46.9 Mar.	11 Mar.	10 Mar.	36.5 Mar.	43.8 Apr.
1884.	51.8 Feb.	34.2 Mar.	47.0 Mar.	7 Mar.	8 Mar.	38.4 Mar.	49.0 Mar.
1885.	39.0 Jan.	29.3 Jan.	40.7 Jan.	8 May	7 May	35.5 May	42.4 Feb.
1886.	51.0 Apr.	34.8 Apr.	48.1 Apr.	5 May	6 May	37.9 May	44.2 May
1887.	48.5 Mar.	35.3 Mar.	46.3 Mar.	23 Mar.	21 Mar.	38.0 Mar.	44.7 Mar.
1888.	45.2 Apr.	34.2 Apr.	42.8 Apr.	22 Apr.	22 Apr.	38.1 Apr.	44.2 Apr.
1889.	34.5 June	26.6 June	34.1 June	30 June	1 July	29.4 July	34.4 July
1890.	48.8 Mar.	35.6 Mar.	47.7 Mar.	27 Mar.	17 Mar.	41.0 Mar.	49.1 Apr.
1891.	46.2 Mar.	34.9 Mar.	44.7 Mar.	4 Apr.	1 Apr.	41.0 Mar.	48.1 Apr.
1892.	48.2 Apr.	34.6 May	45.8 May	1 June	1 June	41.9 June	48.4 June
1893.	49.3 May	35.2 May	48.0 May	29 May	29 May	41.8 May	48.3 May
1894.	37.0 Feb.	29.4 Feb.	38.0 Feb.	24† Feb.	25 Feb.	34.3 Mar.	40.9 Apr.
1895.	33.3 Mar.	24.0 Jan.	31.2 Mar.	1 Apr.	2 Apr.	25.9 Apr.	31.7 Apr.
1896.	39.2 Apr.	29.5 Apr.	38.4 Apr.	19 Apr.	20 Apr.	33.2 Apr.	39.0 Apr.
1897.	51.6 Mar.	37.1 Mar.	51.8 Apr.	29 Mar.	29 Mar.	44.5 Mar.	53.3 Apr.
1898.	49.8 Apr.	37.3 Apr.	49.1 Apr.	19 Apr.	21 Apr.	44.4 Apr.	49.4 Apr.
1899.	46.2 Mar.	35.3 Mar.	46.9 Apr.	15 Apr.	17 Apr.	41.6 Apr.	47.3 Apr.
1900.	39.2 Mar.	29.5 Mar.	38.1 Mar.	25 Mar.	25 Mar.	33.0 Mar.	38.0 Mar.
1901.	43.2 May	32.1 May	41.6 May	12 May	13 May	36.4 May	41.5 May
1902.	42.2 Mar.	30.8 Mar.	39.6 Mar.	28 Mar.	29 Mar.	35.0 Apr.	41.2 Apr.
1903.	50.6 Mar.	40.1 Mar.	51.0 Mar.	27 Mar.	27 Mar.	46.5 Mar.	51.8 Mar.
1904.	49.1 Apr.	39.0 Apr.	47.7 Apr.	19 Apr.	20 Apr.	42.5 Apr.	46.9 Apr.
1905.	38.6 May	29.0 Mar.	37.8 May	3 June	3 June	36.5 June	40.8 June
1906.	46.9 Apr.	37.0 Apr.	47.0 Apr.	22 Apr.	23 Apr.	43.7 Apr.	47.2 Apr.
1907.	50.4 Jan.	40.3 Feb.	50.4 Feb.	8 Feb.	8 Feb.	46.3 Feb.	49.7 Feb.
1908.	45.6 Mar.	35.6 Mar.	45.2 Mar.	2 June	2 June	44.1 June	47.9 June
1909.	47.3 Mar.	38.6 Mar.	47.7 Mar.	28 Mar.	29 Mar.	44.4 Mar.	48.1 Apr.
Extreme.....	52.2	40.3	51.8	53.0	49.1	46.5	52.3

NOTE.—Where the maximum occurred on more than one date the first only is given.

\*Also on May 10.

†Also on March 29.

‡Also on March 30.













Bulletin No. 29.—W. B. No. 403.

Issued December 2, 1911.

**U. S. DEPARTMENT OF AGRICULTURE,  
WEATHER BUREAU.**

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**A COURSE IN METEOROLOGY AND  
PHYSICAL GEOGRAPHY.**

**BY**

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**Published under direction of WILLIS L. MOORE, Chief U. S. Weather Bureau.**

Copies of this publication may be procured from the  
Superintendent of Documents, Government Printing  
Office, Washington, D. C., for 20 cents each.

**WASHINGTON:  
GOVERNMENT PRINTING OFFICE.  
1911.**

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## LETTER OF TRANSMITTAL.

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UNITED STATES DEPARTMENT OF AGRICULTURE,  
WEATHER BUREAU, OFFICE OF THE CHIEF,  
*Washington, D. C., August 1, 1911.*

Hon. JAMES WILSON,  
*Secretary of Agriculture.*

SIR: I have the honor to transmit herewith a paper entitled "A Course in Meteorology and Physical Geography," which has been prepared by Prof. W. N. Allen, of the Tacoma High School, Tacoma, Wash.

Most of this course treats of meteorology, to which the other portions are cognate and introductory. If published, it would be of value to the Weather Bureau, both indirectly by increasing the attention given to meteorology in our high schools and also directly by guiding the younger men of the service in their elementary studies. I therefore recommend its publication as Weather Bureau Bulletin No. 39.

Very respectfully,

WILLIS L. MOORE,  
*Chief U. S. Weather Bureau.*

Approved.

JAMES WILSON,  
*Secretary.*



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# A COURSE IN METEOROLOGY AND PHYSICAL GEOGRAPHY.

## SYNOPSIS.

---

### ASTRONOMICAL.

#### I. SUBJECT MATTER.

##### A. SOLAR SYSTEM.

1. Bodies of solar system.
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  3. Satellites.
  4. Asteroids.
  5. Comets.
  6. Meteors.
2. Diagram of solar system.
3. Formation of solar system.
  1. Nebular theory.
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3. Measurements, etc.
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  3. Longitude.
  4. Zones.
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  6. Time.
  7. Surveys.
4. Diagrams of earth.
  1. Earth.
  2. Change of seasons.

#### II. LABORATORY EQUIPMENT.

##### A. REFERENCE BOOKS.

- |                               |                                |
|-------------------------------|--------------------------------|
| 1. Story of the Solar System. | 6. Earth's Beginnings, Ball.   |
| 2. Realm of Nature.           | 7. Tarr's Physical Geography.  |
| 3. Young's Astronomy.         | 8. Dryer's Physical Geography. |
| 4. Moulton's Astronomy.       | 9. Salisbury's Physiography.   |
| 5. Newcomb's Astronomy.       | 10. Solar System, Poor.        |

##### B. APPARATUS, ETC.

- |                       |                            |
|-----------------------|----------------------------|
| 1. Rotator.           | 7. Globes.                 |
| 2. Centrifugal hoops. | 8. Sun board.              |
| 3. Governor.          | 9. Astronomical board.     |
| 4. Glass globe.       | 10. Charts, drawings, etc. |
| 5. Tellurian.         | 11. Mariner's compass.     |
| 6. Stereopticon.      | 12. Stereopticon slides.   |



**1. ATMOSPHERIC TEMPERATURE.****I. SUBJECT MATTER.****A. ORIGIN, COMPOSITION, ETC.**

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      3. Effects upon life.
    3. Periodical variations.
      1. Representation.
        1. Daily thermal lines.
        2. Yearly graphic lines.
      2. Extreme variations.
      3. Modifying influences.
      4. Effects upon life.

## II. LABORATORY EQUIPMENT.

## A. REFERENCE BOOKS.

- |                                     |                                |
|-------------------------------------|--------------------------------|
| 1. Davis's Elementary Meteorology.  | 6. About the Weather.          |
| 2. Waldo's Elementary Meteorology.  | 7. Tarr's Physical Geography.  |
| 3. Realm of Nature.                 | 8. Works on Physics.           |
| 4. Story of Atmosphere.             | 9. Dryer's Physical Geography. |
| 5. Moore's Descriptive Meteorology. | 10. Salisbury's Physiography.  |

## B. APPARATUS.

- |                   |                             |
|-------------------|-----------------------------|
| 1. Ball and ring. | 6. Maximum thermometers.    |
| 2. Circulation.   | 7. Minimum thermometers.    |
| 3. Convection.    | 8. Fahrenheit thermometers. |
| 4. Conductometer. | 9. Centigrade thermometers. |
| 5. Stereopticon.  | 10. Stereopticon slides.    |

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  2. North and south.
6. Relations of pressure to:
  1. Weather conditions.
  2. Temperature changes.
  3. Effects upon life.

## II. LABORATORY EQUIPMENT.

## A. REFERENCE BOOKS.

- |                                     |                               |
|-------------------------------------|-------------------------------|
| 1. Davis's Elementary Meteorology.  | 6. About the Weather.         |
| 2. Waldo's Elementary Meteorology.  | 7. Tarr's Physical Geography. |
| 3. Story of Atmosphere.             | 8. Works on Physics.          |
| 4. Realm of Nature.                 | 9. The Weather, Abercromby.   |
| 5. Moore's Descriptive Meteorology. | 10. Salisbury's Physiography. |

**B. APPARATUS, ETC.**

- |                        |                         |
|------------------------|-------------------------|
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| 3. Barograph.          | 7. Air pumps.           |
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  3. Movements, (1) rotary, (2) progressive.
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3. Special winds.
  1. Land and sea breezes, daily.
  2. Monsoons, India and Spain, seasonal.
  3. Mountain and desert winds.
  4. Hurricanes, typhoons, and tornadoes.

**B. RELATION TO CLIMATE AND LIFE.**

**II. LABORATORY EQUIPMENT.**

**A. REFERENCE BOOKS.**

- |                                     |  |
|-------------------------------------|--|
| 1. Davis's Elementary Meteorology.  | 6. Realm of Nature.                      |
| 2. Waldo's Elementary Meteorology.  | 7. Tarr's Physical Geography.            |
| 3. About Weather.                   | 8. Dryer's Physical Geography.           |
| 4. Treatise on Winds.               | 9. Salisbury's Physiography.             |
| 5. Moore's Descriptive Meteorology. | 10. Whirlwinds, cyclones, and tornadoes. |

**B. APPARATUS, ETC.**

- |                             |                          |
|-----------------------------|--------------------------|
| 1. Black globe (18 inches). | 4. Convection apparatus. |
| 2. Wind vane.               | 5. Mariner's compass.    |
| 3. Anemometer.              | 6. Stereopticon slides.  |

**IV. ATMOSPHERIC MOISTURE.**

**I. SUBJECT MATTER.**

- 1. Evaporation.**
  1. Favorable condition.
  2. Practical importance.
  3. Relative and absolute humidity.
    1. Means of determining, instruments, etc.
    2. Relation to temperature.
    3. The "dew point" table.
  4. Effects in relation to life.
- 2. Condensation of moisture.**
  1. Cloud forms:
    1. Primary and secondary forms.
    2. Formation and distribution.
  2. Fog forms.
- 3. Precipitation of moisture.**
  1. Governing law.
  2. Controlling conditions.
    1. Convection currents.
      1. Thunderstorms.
      2. Low pressure.
      3. Volcanoes.
      4. Doldrums.
    2. Intercepting mountains.
    3. Intermingling winds.
    4. Land and sea breezes.
    5. Northerly winds, drifts.
  3. Distribution and quantity in—
    1. Wind belts.
    2. Storm zones.
- 4. Crystallization of vapor.**
  1. Frost.
  2. Snow.

**II. LABORATORY EQUIPMENT.**

**A. REFERENCE BOOKS.**

- |                                    |                                     |
|------------------------------------|-------------------------------------|
| 1. Davis's Elementary Meteorology. | 5. "Snow Crystals."                 |
| 2. Waldo's Elementary Meteorology. | 6. Tarr's Physical Geography.       |
| 3. "Cloud Forms," Sigsbee.         | 7. Salisbury's Physiography.        |
| 4. "Cloud Studies," Clayden.       | 8. Moore's Descriptive Meteorology. |

**B. APPARATUS, ETC.**

- |                 |                                 |
|-----------------|---------------------------------|
| 1. Rain gage.   | 5. United States cloud charts.  |
| 2. Hygrometer.  | 6. Cloud photographs.           |
| 3. Evaporators. | 7. United States storm signals. |
| 4. Condensers.  | 8. Stereopticon slides.         |

**THE OCEAN.**

**I. SUBJECT MATTER.**

1. Distribution of oceanic water.
2. Surface temperature.
3. Movements of the ocean.
  1. Wind and storm waves.
  2. The tides.
    1. Periodicity and causes.
    2. Kinds and illustrations.
    3. Relation to planets.
    4. Cotidal lines.
    5. Relation to commerce.
  3. Ocean currents.
    1. Nature and causes.
    2. Relation to winds and temperature.
    3. Distribution and illustrations.
    4. Effect upon climate.
4. Relations to life.
  1. Commerce.
  2. Food supply.
  3. Water supply.
  4. Drainage.
  5. Climate.

**II. LABORATORY EQUIPMENT.**

**A. REFERENCE BOOKS.**

- |                               |                          |
|-------------------------------|--------------------------|
| 1. Physical Geographies.      | 4. Geography of the Sea. |
| 2. Land and Sea.              | 5. Ocean Tides.          |
| 3. Pilot Charts, Tide Tables. | 6. Astronomy.            |

**B. APPARATUS, ETC.**

- |                            |                       |
|----------------------------|-----------------------|
| 1. Demonstration on table. | 3. Charts, maps, etc. |
| 2. Stereopticon slides.    |                       |

**EXERCISE I. THE GLOBE.**

**I. DIRECTIONS, ETC.**

1. Draw upon unruled paper colored globe about 4 inches in diameter from actual inspection of globe. (2) Incline globe toward right  $23\frac{1}{2}$  degrees. (3) Use protractor to determine angles. (4) Read Realm of Nature, pages 78-80, or Moore, pages 69-74.

2. Place upon drawing in proper positions following lines with names: (a) Axis, (b) equator, (c) tropics, (d) ecliptic, (e) meridians, (f) polar circles. (2) Test accuracy of work by comparing it with standard globes.

3. Place upon globe names and widths in degrees of following zones: (a) North Frigid, (b) South Frigid, (c) North Temperate, (d) South Temperate, (e) Torrid.

4. Determine following points from actual inspection of mariner's compass: (a) North, (b) south, (c) east, (d) west, (e) northeast, (f) southeast, (g) northwest, (h) southwest. (2) Name objects that are situated (a) north, (b) south, etc., of high school. (3) State direction of high school from home.

5. Record daily for month wind directions and conditions of sky, whether (a) clear, (b) cloudy, or (c) partly cloudy. (2) Use cross-ruled paper, mariner's compass, and wind vane upon roof. (3) Read Chapter IX, Salisbury, page 60, Realm of Nature, or Appendix F, Tarr. (4) Prepare summary. (5) Determine from charts where magnetic poles, north and south, are located. (6) Locate line of no variation in America.

## II. WRITTEN REVIEW.

1. Define names in Nos. 2 and 3. (2) How is degree upon circle determined? (3) Upon what does length of degrees depend? (4) How do degrees of longitude differ in length from degrees of latitude? (5) Insert table, page 25, Dryer, and explain.

2. Compare inclination of earth's axis with (a) position of tropics, (b) polar circles, and (c) widths of Frigid and Torrid Zones. (2) Where would polar circles and tropics be located if earth's axis were inclined 45 degrees, 20 degrees, 10 degrees, or 0 degrees? (3) State widths of zones in each case.

3. State where vertical sun would shine continuously if earth were not inclined upon its axis. (2) Use globe suspended from axis and light to illustrate. (3) Define (a) latitude and (b) longitude. (4) State (a) from what lines latitude and longitude are reckoned and (b) greatest number of degrees in each. (5) Give approximate longitude, and latitude of this city.

4. Which way does earth rotate? (2) Give proofs. (3) How long does it take to rotate once? (4) Show by use of rotator and centrifugal hoops effects of rotation upon shape of earth. (5) Illustrate by means of light and globe effects of rotation upon distribution of sunlight and heat. (6) Show by use of globe relation between longitude and time.

5. Find approximate difference in longitude and difference in time between Tacoma and New York. (2) Use tellurian, or map, and read Salisbury, page 311. (3) Locate parallel 40 or 45 degrees north. (4) State near or through what cities line passes. (5) Locate upon map and make sectional diagram, 6 by 6 inches, of township 18 north and range 4 east; number sections. (6) Subdivide section 16 into quarters. (7) Locate in red upon diagram and describe in words northeast quarter of section 16. (8) How is land usually described in deeds and tax receipts? (9) Use map of State or United States.

6. State difference between "Magnetic north" and "Polar north." (2) About how many degrees and in what direction is "declination" of magnetic needle in this city? (3) State where line of no variation is located in America.

## III. REFERENCE BOOKS.

1. Tarr's Physical Geography, Appendix A and B.
2. Young's Astronomy, Chapters III, IV.
3. Moulton's Astronomy, Chapter VI.
4. Salisbury's Physiography, Chapters IX, X.
5. Realm of Nature, Chapter IV.
6. Dryer's Physical Geography, Chapter I.
7. Story of Solar System, Chapter V.
8. Maps of State or World.

**EXERCISE II. CHANGE OF SEASONS.**

**I. DIRECTIONS, ETC.**

1. Draw upon unruled paper rectangular figure 3 by 6 inches lengthwise of page. (2) Divide figure into eight squares  $1\frac{1}{2}$  inches each.

2. Construct upon rectangle an ellipse, by using diagonal of one square for radii of side arcs, and diagonal of two squares for upper and lower arcs. (2) Extend middle lines of rectangle to intersect ellipse.

3. Draw upon points of intersection globes  $1\frac{1}{2}$  inches in diameter, to represent earth (a) at autumnal and vernal equinoxes, and (b) at winter and summer solstices. (2) Make globes similar to globe in exercise No. 1.

4. Locate sun near center of diagram. (2) See that globe leans  $23\frac{1}{2}$  degrees toward right. (3) Make slanting and vertical rays of sun in red. (4) See that sun's rays touch earth in right latitudes. (5) Test accuracy of work by using tellurian or astronomical board.

5. Place upon globe circles and belts as in exercise No. 1. (2) Represent night by shading globe. (3) Letter principal points of diagram A, B, C, D. (4) Date each point to correspond with season represented. (5) Indicate directions of earth's movements by means of arrows. (6) See Moore, page 70, or Waldo, page 73.

**II. WRITTEN REVIEW.**

1. State difference between ellipse and circle. (2) What is meant by "Major" and "Minor" diameters of ellipse? (3) State upon which diameter earth is on June 21 and December 21. (4) What are terminal points of diameter called? (5) State which point is nearest sun. (6) Read Salisbury, page 810.

2. State which way earth leans in respect to sun in June and December. (2) State when earth is farthest from sun. (3) Explain why it is warmer at Cancer in June than in December. (4) Use tellurian to illustrate. (5) Measure astronomical board. (6) Read Salisbury, Chapter X.

3. How many degrees of earth is covered by sunshine at one time? (2) How far and in what direction do extreme slanting rays extend from vertical rays? (3) Test answers by comparing them with tellurian.

4. State definitely three conditions that cause change of seasons. (2) Test accuracy of statements by use of tellurian. (3) Explain why length of day and night varies.

5. State latitude of vertical and extreme slanting rays at A. (2) Name seasons at each tropic, and the equator at A, also (3) comparative length of day and night, and (4) condition of light at each pole at A. (5) Do likewise with B, C, and D in separate paragraphs.

**III. REFERENCE BOOKS.**

1. Tarr's Physical Geography, Appendix A and B.
2. Waldo's Elementary Meteorology, Chapter II.
3. Realm of Nature, Chapter V.
4. Moore's Descriptive Meteorology, Chapter VII.
5. Young's Astronomy, Chapter IV.
6. Dryer's Physical Geography, Chapter I.
7. Salisbury's Physiography, Chapter X.
8. Diagrams upon Wall.



**EXERCISE III. SOLAR SYSTEM.**

**I. DIRECTIONS, ETC.**

1. Draw full-page diagram showing (a) relative positions, (b) relative sizes of planets in solar system. (2) Indicate direction of movements of planets by means of arrows. (3) Use tellurian. (4) See Tarr, figure 8, for radii, also Yagg's Chart of Solar System.

2. Draw diagram showing relative size of planets. (2) Insert diameters in red. (3) See Story of Solar System, page 11, or Tarr, pages 4 and 5.

3. Make table, full width of page, showing following summary of facts relating to bodies in solar system.

*General summary of solar system.*

No.	Planet.	Density.	Dist.	Rot.	Rev.	Incl.	No. Sat.	Diam.	Etc.

4. Abbreviate items in summary wherever possible. (2) See Young, page 402, or Story of Solar System, page 182, for form of diagram and summary of facts.

5. Draw diagram showing inclination of each planet. (2) Draw in black with inclination axis in red. (3) Represent each planet by means of circle, 2 inches in diameter. (4) See Story of Solar System, page 9. (5) Use protractors.

6. Insert "Bode's Law" with full explanation beneath. (2) See Young, page 190, or Realm of Nature, page 84. (3) Note space between Mars and Jupiter by red circle in diagram No. 1.

**II. WRITTEN REVIEW.**

1. Name proofs that planets are spherical in form. (2) State probable cause. (3) Refer to experiments with rotator and accessories in Exercise I.

2. Name planets according to size. (2) See summary and diagrams. (3) Which planet is densest? (4) Which is least dense?

3. State observation between density of planet and its distance from sun. (2) See summary.

4. Name planets according to distance from sun. (2) See diagrams.

5. Explain "Bode's Law." (2) State wherein it seems to be deficient. (3) Refer to diagram of solar system.

6. State what is thought to be origin of asteroids.

7. What is your observation concerning direction of rotation and revolution of planets?

8. State whether planets rotate and revolve in same direction.

9. State difference between comets and meteors. (2) Planets and suns.

10. State observation concerning direction and inclination of planets. (2) State what inclination of axis has to do with (a) change of season, (b) length of day and night, and (c) width of zones.

**III. REFERENCE BOOKS.**

1. Tarr's Physical Geography, Chapter I.
2. Tarr's Physical Geography, Appendix A.
3. Dryer's Physical Geography, Chapter I.
4. Moore's Descriptive Meteorology, Chapter IV.
5. Young's Astronomy, Chapter I.
6. Realm of Nature, Chapters V and VI.
7. Story of Solar System.
8. Salisbury's Physiography, Chapter X.

### EXERCISE IV. NEBULAR HYPOTHESIS.

#### I. DIRECTIONS, ETC.

1. State briefly, in series of paragraphs, main features of nebular hypothesis. (2) See Young, page 336, and Realm of Nature, page 92.
2. Make series of drawings, about 4 inches in diameter, to illustrate nebular hypothesis. (2) Make each drawing with brief explanatory statements upon sheet of unruled paper. (3) See nebulae in references.
3. Write explanatory notes of each drawing upon ruled paper, immediately before or after drawings. (2) See drawings upon wall and illustrations of nebulae in Young's Astronomy, page 336.
4. State clearly in separate paragraphs purpose of following experiments: (a) Rotating hoops, (b) rotating governor, (c) rotating and revolving balls, and (d) rotating liquids in glass globe. (2) Make drawings of experiments to accompany each paragraph.

#### II. WRITTEN REVIEW.

1. Give some reasons why nebular hypothesis is generally accepted. (2) See Young's Astronomy, page 347.
2. Explain following facts regarding planets by means of nebular hypothesis: (a) Shape, (b) density, (c) movements, (d) composition, and (e) condition in respect to heat. (2) Mention experiments in connection with explanation.
3. Read what is said in reference books concerning "Nebulae." (2) Give brief summary of readings. (3) State what bearing observed nebulae have upon nebular theory.
4. State what seems to be chief cause in changing (a) gases into liquids or solids, (b) in producing spherical form of planets, (c) in separating bodies into parts. (2) Give illustration by referring to experiments.
5. State what is probable condition of moon. (2) What is likely to become of oceans and atmosphere of earth in time? (3) What will probably become of sun's heat? (4) Of life upon earth?

#### III. REFERENCE BOOKS.

1. Tarr's Physical Geography, Chapter I.
2. Tarr's Physical Geography, Appendix A.
3. Dryer's Physical Geography, Chapter I.
4. Young's Astronomy, Chapters I, II.
5. Moulton's Astronomy.
6. Story of the Solar System.
7. Realm of Nature, Chapters V, VI.
8. Yagg's Charts.

### EXERCISE V. THE ATMOSPHERE.

#### I. DIRECTIONS, ETC.

1. Give short description of origin of atmosphere. (2) State briefly what is likely to become of earth's atmosphere in time. (3) Read Story of Atmosphere, page 9, Davis, pages 2-8, or Moore, Chapter I.
2. Insert table, page 275, Dryer. (2) State beneath table three things table is designed to show. (3) State which substance in air is (a) lightest, (b)

heaviest, (c) most abundant, (d) most beneficial to plants, (e) most injurious to animals. (4) Mention effects of oxygen upon life. (5) Give brief account of nitrogen, its uses, etc.

3. Name five sources of dust particles. (2) Read references to dust. (3) State how dust is distributed through air. (4) Insert tables, page 24, Story of Atmosphere. (5) State what each table is designed to show. (6) Read Moore, pages 29-33.

4. Make colored drawing on unruled paper full length of page of prism and spectrum. (2) Test colors by comparing them with solar spectrum or colored disks. (3) Read Realm of Nature, page 36, and Story of Atmosphere, page 147. (4) Substitute raindrop for prism in drawing and draw rainbow. (5) Experiment with prism.

5. State effect of dust particles upon (a) color, (b) heat, and (c) light of atmosphere. (2) Explain (a) color of sky, and (b) twilight and dawn. (3) Read Davis, Chapter IV, or Tarr, page 119.

6. Discuss two classes of microbes. (2) State conditions under which microbes thrive. (3) Name some benefits and dangers of microbes. (4) Name some simple means of preventing microbes. (5) Read "Bacteria, etc.," by Conn, Waldo, page 9, or Moore, page 27.

7. Insert upon unruled paper figure 18, page 74, Waldo, or figure 253, page 277, Dryer, lengthwise of page. (2) Substitute Mount Tacoma for mountains in figure. (3) Make drawing three times size of figure in book. (4) State beneath figure, four things figure is designed to show.

## II. WRITTEN REVIEW.

1. How would slight variation in quantity of oxygen or nitrogen affect life of animals? (2) Read Story of Atmosphere, or Moore, Chapter II.

2. Where is carbon dioxide most plentiful? (2) Was it ever more plentiful? (3) Give reasons for each statement. (4) Read Realm of Nature, page 263, and Story of Atmosphere, page 20. (5) Give brief account of some noted "Death gulch." (6) State briefly what makes such gulches dangerous. (7) Read Davis, pages 5-6.

3. Name five uses of dust particles. (2) Where is dust most plentiful? (3) State briefly chief uses and work of atmosphere. (4) Explain why water vapor floats in air. (5) See Table No. 1.

4. Define color. (2) Name seven prismatic colors. (3) Explain formation of (a) colored sunsets, and (b) rainbows. (4) Explain formation of spectrum and rainbow.

5. Account for presence of water vapor in air. (2) Mention its uses. (3) Does water vapor weight more or less than dry air? (4) Give some proofs.

6. State how nebular hypothesis explains origin of atmosphere. (2) Read Realm of Nature, pages 92-94, or Moore, Chapter IV.

## III. REFERENCE BOOKS.

1. Story of Atmosphere, Chapters I, II.
2. Waldo's Elementary Meteorology, Chapter I.
3. Davis's Elementary Meteorology, Chapters I-IV.
4. Moore's Descriptive Meteorology, Chapters I, II, III.
5. Realm of Nature, Chapter VII.
6. Tarr's Physical Geography, Chapter XII.
7. Dryer's Physical Geography, Chapter XXII.
8. Salisbury's Physiography, Chapters XI, XII.

**EXERCISE VI. HEAT.****I. DIRECTIONS, ETC.**

1. Read references to heat. (2) Keep for time end of wire in flame. (3) Test temperature of other parts. (4) Make drawings to illustrate experiments upon upper part of unruled sheet and explanatory notes on lower half. (5) Define (*a*) radiation, (*b*) absorption, and (*c*) conduction of heat. (6) Name some natural objects that are good (*a*) radiators, (*b*) absorbers, and (*c*) conductors of heat.

2. Burn small quantity of gasoline upon water in test tube and hold wire above flame. (2) Test temperature of water beneath flame and wire above. (3) Explain difference in temperature of water and wire. (4) Make, letter, and explain drawing. (5) Define (*a*) reflection and (*b*) absorption of heat.

3. Pass metal ball through ring. (2) Heat ball and try to repeat. (3) Cool ball or heat ring and repeat. (4) Observe effect of heat and of cold upon size of solids. (5) Make, letter, and explain drawings as in No. 1.

4. Place test tube with water over flame. (2) Note change in volume of water. (3) Make two drawings upon upper part of paper to illustrate effect of heat upon volume of liquids. (4) What causes water to boil over?

5. Hold corked test tube over flame. (2) Observe results. (3) Make, letter, and explain two drawings. (4) What effect has heat upon volume of gases? (5) What causes gas tanks or boilers to explode?

6. Imagine small quantity of ice or sulphur in dish over flame. (2) Note changes in form. (3) What is it that changes (*a*) solids to liquids and (*b*) liquids to gases? (4) Name three forms of matter. (5) Make and explain two drawings.

7. Place side of bent tube, convection apparatus, containing liquid over flame. (2) Indicate direction of circulation by means of colored arrows in drawing half page size. (3) Define convection. (4) What causes water to circulate? (5) What causes ocean currents?

8. Place flame in left tube of convection apparatus. (2) Hold lighted torch above each tube. (3) Make drawing on upper part of page. (4) Indicate direction of air currents by colored arrows. (5) What causes air to circulate? (6) Read Moore, page 51.

**II. WRITTEN REVIEW.**

1. Define matter. (2) Discuss structure of matter. (3) Read Realm of Nature, page 27. (4) Give examples of each form of matter. (5) State effect of intense cold upon (*a*) water and (*b*) air. (6) Read Moore, page 26.

2. Define heat. (2) Discuss four original sources of heat. (3) State which source is most important to earth. (4) State effect of intense heat upon (*a*) solids and (*b*) liquids.

3. Explain why volume of warm air or water should weigh less than same volume of cold air or water. (2) State why smoke rises in flue.

4. Explain why cold water flows toward the fire box and warm water rises in water tank. (2) Give location of hottest and coldest belts upon earth. (3) Which way does air and water of globe flow in respect to heat and cold belts? (4) See maps of winds and ocean currents in reference books.

5. Which is better reflector, land or water surface? (2) Explain why continents are warmer in summer than oceans.

6. Explain in separate paragraphs and give examples in nature of (*a*) radiation, (*b*) absorption, (*c*) reflection, (*d*) conduction, (*e*) convection. (2) State what causes liquids and gases to circulate. (3) State by what means large buildings and ocean steamers are usually ventilated.

### III. REFERENCE BOOKS.

1. Realm of Nature, Chapters I, II, III.
2. Story of Atmosphere, Chapter IV.
3. Moore's Descriptive Meteorology, Chapters V, VII.
4. Books on Physics.
5. Davis's Elementary Meteorology, Chapter III.
6. Waldo's Elementary Meteorology, Chapter II.
7. Salisbury's Physiography, Chapter XIII.

### EXERCISE VII. THERMOMETERS.

#### I. DIRECTIONS, ETC.

1. Read what is said in references concerning thermometers and thermographs. (2) Record upon cross-ruled paper daily for month, temperature of room by means of (a) Fahrenheit and (b) Centigrade thermometers.

2. Keep over flame thermometer tube containing small quantity of air and mercury, until mercury fills tube. (2) Seal tube and allow mercury to cool. (3) What is space above mercury called? (4) Make upon upper part of page three drawings of experiments about 4 inches long. (5) Explain drawings separately upon lower part of page.

3. Keep lower part of tube submerged in cracked ice or snow until contraction of mercury ceases. (2) Mark point of minimum contraction of mercury. (3) What is point called? (4) Make drawing of experiment and explain beneath.

4. Suspend thermometer tube in long-neck flask containing boiling water. (2) Cork neck of flask. (3) Mark maximum expansion of mercury in tube. (4) What is point called? (5) Make drawing of experiment and explain beneath.

5. Draw two thermometers, Fahrenheit and Centigrade, 25 centimeters long, upon metric ruled or blank paper. (2) Make drawings in form of rectangle. (3) Make upper and lower lines of diagrams indicate boiling and freezing points of water, and 18 centimeters apart. (4) Grade each instrument by dividing space between boiling and freezing points into required number of parts. (5) See that readings of thermometers correspond. (6) Notice that thermometers register actual temperature of room.

6. Draw from inspection maximum and minimum thermometers. (2) Explain drawings. (3) See that readings in drawings are same as readings upon thermometers. (4) How does steel index work? (5) Mention use of constriction. (6) Read Davis, page 60.

#### II. WRITTEN REVIEW.

1. Describe in separate paragraphs kinds of material necessary for construction of thermometers. (2) Give reasons for use of each material. (3) State how each thermometer tube is graded.

2. Describe (a) how vacuum is formed in thermometer tube and mention its use; (b) how freezing point is determined; (c) how boiling point is determined; (d) how one degree upon each thermometer tube is determined.

3. Deduce formulas for transposing terms of one thermometer into terms of another. (2) Test formulas by transposing daily readings of one thermometer into readings of another thermometer. (3) Use daily record No. 1.

4. Name some advantages or uses of maximum and minimum thermometers. (2) Give short description of construction and use of each instrument. (3) What kind of liquid is used in minimum thermometer? Why?

5. What principle is used in construction of thermometers? (2) For what does zero stand upon each instrument? (3) What is meant by absolute zero? (4) What is cold? (5) See paper thermometer on wall for low readings and absolute zero; also Moore, pages 54-55.

### III. REFERENCE BOOKS.

1. Tarr's Physical Geography, Appendix G.
2. Waldo's Elementary Meteorology, pages 31-33.
3. Davis's Elementary Meteorology, Chapter V.
4. Moore's Descriptive Meteorology, Chapter VI.
5. Realm of Nature, pages 341-342.
6. Story of Atmosphere, page 39.
7. Dryer's Physical Geography, Appendix.
8. Salisbury's Physiography, Chapter XIII.

### EXERCISE VIII. DAILY CHANGE IN TEMPERATURE.

#### I. DIRECTIONS, ETC.

1. Draw thermograph, full-page size, from inspection of instrument. (2) Letter principal parts of drawing. (3) Mention use of each part. (4) Make cylinder, full size. (5) Indicate direction of movement of cylinder by means of arrows. (6) State what part of thermograph expands and contracts. (7) What turns cylinder? (8) See thermograph and read Davis, page 58.

2. Notice how sheet upon cylinder is lined and numbered. (2) State what lines and spaces between lines represent. (3) What does line made by pen upon sheet represent? (4) What is sheet and pen line called?

3. Draw from thermal sheets upon sheet of metric paper two thermal lines in red. (2) Make first line to represent changes in temperature for two consecutive clear days. (3) Make second line to represent two consecutive cloudy days. (4) See thermal sheets for clear and cloudy weather. (5) Begin lines at midnight. (6) Allow one centimeter for two hours. (7) One centimeter for 5°. (8) Date lines as per thermal sheets. (9) Fold sheet lengthwise. (10) Use upper and lower halves separately.

4. State when (a) minimum and (b) maximum temperature of each day occurs. (2) Find difference in daily extremes of temperature. (3) What is difference called? (4) Compare range of temperature during clear and cloudy weather. (5) Read Dryer, page 28, or Tarr, page 241.

5. Insert table, page 28, Waldo. (2) Illustrate table by drawing upper part of figure 392 in Tarr full width of page. (3) Make lines represent sun's rays at angles given in table, and 1 centimeter in width. (4) Place table and drawing on same page. (5) State three facts table is designed to show. (6) See diagrams upon wall.

6. Select from summer "weather map," and give date, (a) 10 interior cities and (b) 10 seaport cities. (2) Find their average (a) maximum, (b) minimum, and (c) range of temperature. (3) Make averages in red. (4) Compare averages in temperature of interior cities with those of seaport cities. (5) Give reasons for difference observed. (6) See form for tabulation on wall.

#### II. WRITTEN REVIEW.

1. State what part of thermograph is substituted for mercury in thermometer. (2) State how change of temperature is communicated to pen. (3) Name some advantages of thermographs. (4) State how thermal sheet is ruled and numbered. (5) How does thermal line show changes in temperature?



2. Express in words ordinary change in temperature for one clear day. (2) Explain fully (a) why maximum temperature occurs about middle of afternoon, and (b) minimum about sunrise. (3) State what you observe concerning (a) maximum, (b) minimum, and (c) range of temperature during clear and cloudy weather. (4) Give reasons for observations.

3. What kind of temperature should be expected (a) upon clear nights in winter, (b) upon clear days in summer? (2) How would low temperature affect water pipes and plants? (3) State what you observe, and give reasons in each case.

4. Compare averages of interior cities with averages of seaport cities. (2) State effect of water bodies and dry places upon (a) maximum, (b) minimum, and (c) range of temperature. (3) Account for differences of temperature between eastern and western Washington. (4) Read Dryer, page 300.

5. State relation between (a) angle of sun and amount of heat received, (b) angle of sun and amount of surface covered, (c) units of atmosphere and amount of heat. (2) See table and illustration in No. 5.

### III. REFERENCE BOOKS.

1. Waldo's Elementary Meteorology, Chapter II.
2. Tarr's Physical Geography, Chapter XII.
3. Dryer's Physical Geography, Chapter XXV.
4. Moore's Descriptive Meteorology, Chapters VI, VII.
5. Story of Atmosphere, Chapter IV.
6. Story of Atmosphere, figures 4, 5.
7. Davis's Elementary Meteorology, Chapter V.
8. Salisbury's Physiography, Chapter XIII.

### EXERCISE IX. SEASONAL CHANGE IN TEMPERATURE.

#### I. DIRECTIONS, ETC.

1. Draw in red, upon chart of world, isotherms for July. (2) Number lines as per chart. (3) Note how thermal numbers increase or decrease in respect to equator. (4) Locate definitely and color places of greatest heat. (5) See thermal charts for July and January in reference books, also charts 2 and 3, Moore.

2. Note whether or not isotherms bend toward or away from equator in crossing continents. (2) Do same in respect to oceans. (3) State what bends observed indicate regarding comparative temperature over land and sea in July.

3. Compare positions of isotherms of  $70^{\circ}$  north and south in respect to equator. (2) Note comparative latitude of same thermal line near eastern and western coasts of continents. (3) Determine whether or not temperature is equal in same latitudes north and south, and east and west.

4. Treat January chart in same manner as July chart, and repeat Nos. 1, 2, 3.

5. Read Tarr, pages 276 to 279, prepare summary with examples to illustrate what is said concerning influence of (a) latitude, (b) altitude, (c) oceans, (d) deserts, and (e) north and south slopes upon temperature. (2) Read Moore, page 115, or Waldo, page 53.

6. Determine, by use of tellurian, latitude of vertical sun on June 21 and December 21. (2) Illustrate same by drawing together in red and black, figures 549 and 551, Tarr. (3) Compare positions of maximum temperature for July and January. (4) Prepare reasons for changes in positions.



## II. WRITTEN REVIEW.

1. State how temperature increases or decreases in respect to latitude. (2) Give reasons. (3) See No. 5, Exercise VIII. (4) Name countries which are hottest in July. (5) Give at least two reasons. (6) Do same in respect to January.

2. State which way thermal lines bend in crossing oceans, in (a) summer, and (b) winter. (2) Do same in respect to continents. (3) Give reasons in each case. (4) Give reasons why thermal lines do not coincide with parallel lines.

3. Compare isotherms south with same isotherms north of equator in respect to regularity. (2) Do same in respect to land and water surfaces. (3) Give reasons for observations.

4. State in separate paragraphs and give examples of influence of (a) altitude, (b) latitude, (c) oceans, (d) winds, (e) ocean currents, (f) clouds, (g) desert, and (h) direction of mountain slopes upon temperature. (2) Give reasons why all places in same latitude do not have same temperature. (3) Define (a) isothermal line, (b) thermal equator. (4) Locate thermal equator and state why so located.

5. State upon what lines sun is vertical June 21 and December 21. (2) Explain why (a) maximum temperature occurs in July and (b) minimum in January. (3) State what causes thermal lines and belts to change positions.

6. Name principal places in North America through which July isotherms of  $60^{\circ}$  passes. (2) Do same with January line of  $60^{\circ}$ . (3) Give reasons for difference in position and regularity of line.

## III. REFERENCE BOOKS.

1. Waldo's Elementary Meteorology, Chapter II.
2. Tarr's Physical Geography, Chapter IV.
3. Story of Atmosphere, Chapter IV.
4. Moore's Descriptive Meteorology, Chapter VII.
5. Realm of Nature, Chapter VII.
6. Davis's Elementary Meteorology, Chapter V.
7. Dryer's Physical Geography, Chapter XV.
8. Salisbury's Physiology, Chapter XIII.

## EXERCISE X. BAROMETERS.

## I. DIRECTIONS, ETC.

1. Record daily for month, upon cross-ruled paper, atmospheric pressure as indicated upon barometer or barograph. (2) Date sheet. (3) Record kind of weather as "Fair," "Cloudy," "Rainy," etc. (4) Continue to record temperatures. (5) Read Ward's Exercises in Elementary Meteorology, Chapter I.

2. Read references concerning barometers and barographs. (2) State what demonstrations with (a) air pump, (b) inverted glass of water, and (c) balances are designed to show. (3) Read Davis, page 82, Moore, pages 127-132, or Waldo, page 75.

3. Fill glass tube about 3 feet long with mercury. (2) Invert filled tube in bowl containing mercury. (3) Observe that end of tube does not rest on bottom of bowl. (4) Notice that mercury has fallen in tube. (5) What is empty space above mercury called? (6) How is it formed? (7) What keeps mercury up in tube?

4. Draw upon metric or unruled paper-bent tube; tube and bowl and stand together. (2) Make tubes about 24 centimeters long and 1 centimeter wide. (3) Make bowl and bend in tube about 4 centimeters across. (4) See apparatus, drawings upon wall, and illustrations in reference books.

5. Grade tubes from 25 to 35 inches by allowing two and one-half centimeters for each inch. (2) See that mercury in bowl and tube is on same level. (3) Measure height of mercury in tubes from surface of mercury in bowl and tube. (4) Compare measurements with actual readings upon standard barometers.

6. Insert table, page 75, Waldo. (2) State what table is designed to show. (3) Determine which weighs more per cubic foot, (a) dry air or water vapor, (b) warm or cold air. (4) How does barometer stand during rainy weather? Why? (5) Read Story of Atmosphere, page 27.

## II. WRITTEN REVIEW.

1. How high is atmosphere supposed to extend? (2) Read Moore, page 8, or Davis, page 13. (3) What is weight or pressure of atmosphere on square inch; on square foot? (4) In which direction is pressure exerted? (5) Refer to experiments.

2. What effect has altitude upon pressure? Why? (2) Give approximate pressure of atmosphere upon summit of Mount Tacoma (14,500 feet) when barometer registers 30 inches at sea level. (3) State effect of water vapor in air upon barometric pressure. (4) Read Moore, page 200, or Davis, page 143.

3. Compare weight of mercury with that of water. (2) How high will water rise in vacuum? Why? (3) How high will mercury rise in vacuum? Why? (4) What causes water to rise in ordinary pumps or tubes? (5) Explain what is meant by suction.

4. State briefly history of barometer. (2) Read Story of Atmosphere, page 25. (3) Describe how vacuum is formed in barometer tube. (4) Mention use of vacuum. (5) Describe how simple barometer is constructed and graded.

5. Compare working of balances with working of barometer. (2) State principle used in construction of barometers. (3) Give reasons for use of long tube. (4) Why is mercury used in barometers?

6. Name practical uses of barometers. (2) Express in inches what constitute (a) high, (b) low, and (c) normal barometers at sea level. (3) State kind of weather indicated by "Low" and by "High" barometers. (4) Give reasons in each case.

## III. REFERENCE BOOKS.

1. Waldo's Elementary Meteorology, Chapter III.
2. Davis's Elementary Meteorology, Chapter VI.
3. Story of Atmosphere, Chapter III.
4. Moore's Descriptive Meteorology, Chapter IX.
5. Tarr's Physical Geography, pages 420-422.
6. Dryer's Physical Geography, Chapter XXVI.
7. Marvin's "Barometers, etc."
8. Salisbury's Physiography, Chapter XV.

## EXERCISE XI. DAILY CHANGE IN PRESSURE.

### I. DIRECTIONS, ETC.

1. Continue to record daily barometric pressure. (2) Record daily whether or not barographic line is "rising," "falling," or "even." (3) Note kind of line associated with unusually "good" or "bad" weather, also with severe "storms" or "violent" winds. (4) Observe barographs daily.

2. Read Davis, page 84, and Moore, page 131. (2) Draw barograph full page size from inspection of instrument. (3) Letter principal parts of drawings. (4) State use of each part. (5) Make cylinder full size. (6) What turns cylinder?

3. Note how sheet upon cylinder is ruled, lettered, and numbered. (2) State what lines and spaces between lines represent. (3) What does line made by pen upon sheet represent? (4) What is sheet and pen line called?

4. Draw from barographic sheets upon metric ruled paper two barographic lines in red. (2) Make first to represent "clear" or "good" weather. (3) Make second to represent "rainy" or "bad" weather. (4) See barographic sheets for "good" and "bad" weather. (5) Begin lines at midnight. (6) Allow 2.5 centimeters per inch. (7) Allow 1 centimeter for six hours. (8) Date lines as per sheets. (9) Fold metric sheets lengthwise. (10) Use upper and lower halves separately.

5. Determine from inspection of lines, interval of time usually between one maximum and another. (2) Compare two barographic lines. (3) State which one has higher pressure. (4) Apply and remove pressure by breathing through attached tube on demonstration barometer. (5) What does demonstration show?

## II. WRITTEN REVIEW.

1. State what part of barograph is substituted for mercury in standard barometer. (2) Name two parts of barograph that correspond to two parts of balances. (3) Which way does cylinder turn in respect to pen?

2. Explain how changes in pressure are communicated to pen. (2) State how barographic line indicates change in pressure. (3) What kind of line indicates (a) "good," (b) "bad," (c) stormy weather, or (d) violent winds?

3. State from inspection of barometric line approximate interval of time usually between maximum and minimum pressures. (2) State how often weather conditions usually change. (3) State what kind of weather is indicated (a) by "rising" barographic line, (b) by "falling" line, (c) by "even" or straight line, (d) by "very steep" or V-shaped line. (4) Read Dryer, page 324.

4. Mention advantages of barographs. (2) Name some practical uses of barographs and barometers to (a) sailors, (b) farmers, (c) mountaineers, (d) builders, and (e) aviators. (3) Explain how altitude is determined by barometers.

5. State effect of atmospheric pressure upon breathing. (2) How does water vapor in air affect barographs? (3) State how barographs indicate increase or decrease in air pressure and change of weather. (4) Give brief description of aneroid barometers. (5) See instrument and read Moore, page 180.

## III. REFERENCE BOOKS.

1. Waldo's Elementary Meteorology, Chapter III.
2. Davis's Elementary Meteorology, Chapter VI.
3. Story of Atmosphere, Chapter III.
4. Moore's Descriptive Meteorology, pages 127-138.
5. Tarr's Physical Geography, pages 420-422.
6. Dryer's Physical Geography, Chapter XXVI.
7. Marvin's "Barometers, etc."
8. Salisbury's Physiography, Chapter XVI.

## EXERCISE XII. SEASONAL CHANGE IN PRESSURE.

### I. DIRECTIONS, ETC.

1. Draw colored isobaric chart of world for July. (2) Number isobaric lines as per chart. (3) Print upon chart word "High" or "Low" in proper areas, north and south. (4) See isobaric charts in reference books.

2. Locate places of maximum and minimum pressures in middle latitudes, north and south. (2) Notice whether high pressures are mostly over land or

sea. (3) Notice in about what latitude high-pressure areas are located. (4) See charts, and Waldo, page 96, or Moore, page 134.

3. Draw isobaric chart of world for January, and repeat as in Nos. 1 and 2.

4. Compare latitude of July high pressure north with January high pressure. (2) Compare their positions in respect to land and water surfaces. (3) Prepare reasons for change observed. (4) What effect has heat upon pressure? (5) Compare extent of high pressure in winter with that in summer.

5. Indicate upon charts wind directions by means of arrows. (2) Observe whether or not surface air moves toward or from high-pressure belts. (3) Note which way winds blow in respect to continents (a) in summer, and (b) in winter. (4) See Realm of Nature, pages 116 and 124, or Waldo, pages 91 and 93.

6. Determine which weighs more per unit volume, warm air or cold air. (2) Note positions of "High" and "Low" pressures in summer and in winter in respect to land and water. (3) Read Story of Atmosphere, page 27, and prepare summary.

## II. WRITTEN REVIEW.

1. State in what ways atmosphere pressure is represented upon charts. (2) What are pressure lines called? (3) In what terms are such lines numbered? (4) What line separates "High" and "Low" pressure areas? (5) What are areas without line called? (6) Read Moore, page 135.

2. Compare extent of surface covered by high pressure in summer with that in winter. (2) Compare temperature over land with pressure over land (a) during winter and (b) during summer. (3) Do same in respect to oceans. (4) State relation of heat and pressure. (5) State why pressure is low in equatorial belt.

3. What effect has heat upon pressure? (2) Explain why pressure belts and line change positions with change of seasons. (3) See barometric charts for July and January. (4) Give example to illustrate answer.

4. Compare summer pressure with winter pressure over continents. (2) How is wind direction indicated upon maps? (3) State which way winds blow in respect to land and water masses in (a) summer and (b) winter. (4) State which way winds blow in respect to high and low pressure areas. (5) Which way streams flow in respect to high and low places.

5. How does warm air compare in weight to cold air? (2) Explain why air rises over hot places and settles over cold places. (3) Why does wind blow toward land in summer and away from it in winter? (4) Why should pressure be greater upon land in winter than in summer?

## III. REFERENCE BOOKS.

1. Davis's Elementary Meteorology, Chapters II-VI.
2. Waldo's Elementary Meteorology, Chapter III.
3. Realm of Nature, pages 116-124.
4. Moore's Descriptive Meteorology, pages 127-138.
5. Story of Atmosphere, Chapter III.
6. Dryer's Physical Geography, Chapter XXVI.
7. Salisbury's Physiography, Chapter XV.
8. Bartholomew's Physical Atlas.

## EXERCISE XIII. PRESSURE AND WINDS.

### I. DIRECTIONS, ETC.

1. Determine average latitude, north and south, of high and low pressure belts for year. (2) See page 96, Waldo, or Moore, page 134. (3) Draw upon chart of world in latitudes given, colored belts, half centimeter wide, to represent

pressures. (4) Place in belts (a) words "High" or "Low" in proper places; also (b) pressures in figures.

2. Indicate by arrows directions of winds in each belt. (2) Note relation between wind directions and pressure belts. (3) Read Tarr, page 255. (4) Rotate black globe from west to east. (5) Note effect of rotation upon wind direction in (a) equatorial, and (b) temperate belts. (6) Read Dryer, pages 306-311, or Moore, page 141.

3. Print upon chart in proper belts, (a) northeast trades, (b) southeast trades, (c) westerlies, and (d) circumpolar. (2) Note wind direction and latitude of each wind belt. (3) Do wind belts change positions? Why? (4) See Davis, page 121, or Moore, page 140.

4. Draw lengthwise, upon lower half of metric ruled paper, cross-section of chart No. 1. (2) Allow 1 centimeter for each 10 degrees of latitude. (3) Allow 2 millimeters for each tenth inch of pressure. (4) Insert pressures in figures in proper latitudes. (5) Indicate wind directions and slopes by lines and arrows. (6) Insert names of winds in proper places. (7) See Davis, page 89, or Waldo, page 97.

5. Describe, by means of cross-section, circulation of atmosphere from equator to poles and return. (2) Give (a) name, (b) direction, (c) latitude and altitude of winds in each belt. (3) State what makes air rise near equator. (4) What makes air settle near 30 and 35 degrees, north and south.

6. Determine what is meant by barometric gradient. (2) How is value of gradient determined? (3) Read Waldo, page 100, Salisbury, page 396, or Moore, page 135. (4) Show meaning by use of cross-section. (5) How does gradient effect velocity of winds? (6) What kind of wind does V-shaped or very steep barographic line represent?

## II. WRITTEN REVIEW.

1. Explain what causes winds. (2) Explain effect of earth's rotation upon wind direction in (a) equatorial and (b) temperate belts. (3) Mention wind directions in each belt, if earth did not rotate. (4) What causes low pressure near equator? (5) What causes high pressure near middle latitudes? (6) What causes low pressure near latitudes 65°, north and south?

2. Give latitudes, (a) directions and (b) character, of following winds and wind belts in separate paragraphs: (a) Trades, (b) antitrades, (c) prevailing westerlies, (d) horse latitudes, (e) circumpolar winds, (f) return westerlies, and (g) belt of calms. (2) Read Davis, page 117, Tarr, pages 258 to 262, or Moore, page 178.

3. State in separate paragraphs effect of winds upon (a) ocean currents, (b) ocean commerce, (c) surface of earth, (d) distribution of moisture, (e) distribution of plant life, (f) equalization of temperature, (g) and general health.

4. Determine by use of cross-section value of gradients for trades and westerlies north. (2) How is velocity of winds indicated upon barometric sheets? (3) Mention some practical uses of winds.

## III. REFERENCE BOOKS.

1. Waldo's Elementary Meteorology, Chapters III-VIII.
2. Realm of Nature, Chapter VIII.
3. Ferrel's "Winds."
4. Moore's Descriptive Meteorology, Chapters IX, X.
5. Davis's Elementary Meteorology, Chapter VII.
6. Dryer's Physical Geography, Chapter XXVI.
7. Story of Atmosphere, Chapter V.
8. Salisbury's Physiography, Chapters XV, XVI.

**EXERCISE XIV. WIND DIRECTIONS AND RAINFALL.**

**I. DIRECTIONS, ETC.**

1. Trace in ink upon chart of world or each continent (a) shore lines, (b) rivers, (c) lakes, and (d) mountains. (2) Indicate in colors and figures upon each continent rainfall for summer. (3) Insert names and indicate wind directions in each belt. (4) Print word "Dry" in red upon places dry for one season and word "Desert" on places dry for years. (5) Insert upon chart words "High" or "Low" in proper places upon oceans, north and south. (6) See charts for wind directions and rainfall.

2. Note general directions of (a) mountains and (b) river systems upon each continent. (2) Determine between what parallels north and south (a) trade winds and (b) prevailing westerlies are situated. (3) State whether or not winds blow toward or away from continents upon eastern or western coasts in (a) trade and (b) westerly belts. (4) Observe whether or not deserts are situated upon "windward" or "leeward" side of mountain ranges. (5) Observe same in respect to rain belts. (6) Note whether or not river systems generally flow with or against prevailing wind directions. (7) Read Dryer, pages 327 to 334; Tarr, pages 22 to 30; or Moore, pages 265 to 266.

3. Draw chart of world or continents for winter and repeat data in Nos. 1 and 2.

4. Draw upon charts of United States or Washington (a) wind directions and (b) rainfall in colors and inches for July and January. (2) See wind charts for summer, Dryer, pages 305 to 330. (3) Note difference in wind directions and rainfall for July and January. (4) State causes of changes. (5) See Government rain charts for summer and winter.

5. Record wind directions daily for month. (2) Use initial letters, as N., S., NE., SW., etc. (3) Use mariner's compass in determining directions. (4) Observe cloud or smoke drift, also wind vane upon roof. (5) Read (a) Salisbury, Chapter IX, (b) Realm of Nature, page 60, or (c) Tarr, Appendix F.

**II. WRITTEN REVIEW.**

1. State definitely where maximum rainfall in North America occurs in winter and in summer. (2) Explain why maximum rainfall occurs at that season and place. (3) In what wind belt is maximum rainfall in winter and in summer?

2. Repeat No. 1 in separate paragraph in respect to each continent.

3. Give directions of river systems on each continent in respect to (a) wind direction and (b) mountain systems. (2) Give reasons why Columbia flows west, Amazon east, Mississippi south. (3) Why should Amazon be larger than Columbia? (4) What winds supply La Plata and Orinoco with water? (5) Read Salisbury, pages 396 to 491.

4. State definitely where and in what wind belt each great desert is situated. (2) Give reason why each desert is so located. (3) During what seasons and by what winds is Nile supplied with water? (4) Read Davis, pages 296 to 310.

5. Locate upon each continent rain and rainless belts, if earth were to rotate from east to west. (2) Describe condition (a) in South America if Andes were upon eastern side of continent, (b) in Australia if mountains were upon western side, and (c) in Washington if there were no Cascade Mountains. (3) Describe wind vane upon roof. (4) Which way does arrow point in respect to wind directions? (5) Read Moore, pages 172 to 176.



## III. REFERENCE BOOKS.

1. Tarr's Physical Geography, Chapter XIV.
2. Dryer's Physical Geography, Chapter XXVIII.
3. Waldo's Physical Geography, Chapters IV-XII.
4. Salisbury's Physiography, Chapter XVI.
5. Davis's Elementary Meteorology, Chapter XII.
6. Realm of Nature, Chapter IX.
7. Moore's Descriptive Meteorology, page 265.
8. Physical Atlas and Maps.

## EXERCISE XV. HIGH AND LOW PRESSURE STORMS.

## I. DIRECTIONS, ETC.

1. Read what is said in references concerning cyclones and anticyclones. (2) Continue to record wind directions. (3) Insert in two columns names and velocities of wind in miles. (4) Read Davis, page 94, or Moore, pages 172-177. (5) Determine from inspection of tables what is meant by wind pressure. (6) Determine relation between wind velocity and pressure. (7) Read references relating to anemometers and prepare summary.

2. Insert enlarged half page, figures 29 and 30, Realm of Nature. (2) Print in red words "High" or "Low" in center of figures. (3) Divide figures into quarters by light pencil lines, north and south, east and west. (4) Indicate position of each quarter by inserting in red proper initial, as SE., SW., NW., or NE.

3. Note (a) wind directions and (b) condition of sky in middle of each quarter of "Low." (2) Note whether or not winds move in or out of low pressure directly or spirally. (3) Observe whether movement is from left or right or otherwise in southern half of "Low." (4) See figures 53 or 58, Davis. (5) Repeat same for "Highs."

4. Insert enlarged upon upper part of paper, figure 292, Dryer, or figure 73, Waldo. (2) Print in centers of whirls words "High" or "Low." (3) Draw pencil line through center of figure and note directions N. and S. (4) Note from figure how winds flow out of high pressure into low pressure in southern halves.

5. Insert upon lower part of page cross and vertical sections of high and low pressure areas, figures 412 and 417, Tarr. (2) Print word "Sky" above each figure and words "High" or "Low" immediately beneath. (3) Note wind directions in center of each pressure. (4) Note relation of barometric line to high and low pressure.

## II. WRITTEN REVIEW.

1. State differences between "Cyclones" and "Anticyclones," or "Low" and "High" pressure storms; use diagrams. (2) Give directions of spiral whirl in southern half and in center of cyclones. (3) Do same with anticyclones. (4) State effect of (a) rising and (b) falling air upon barometer.

2. In what direction do low-pressure storms move in (a) Equatorial and (b) Temperate Zones? (2) Read Dryer, page 318. (3) What part of storm is front? (4) Standing with back to wind, where is center of low pressure, on right or left?

3. State how coming of low-pressure storms are indicated by (a) barograph, (b) thermograph, (c) wind direction, (d) condition of sky. (2) Do likewise



with high-pressure storms. (3) What part of low-pressure storms are most dangerous? (4) What instrument is most useful in indicating coming storms?

4. State what wind velocity is considered dangerous to buildings or shipping. (2) State pressure per square foot at velocity mentioned. See tables, Davis or Moore. (3) What is relation between wind velocity and pressure? (4) Explain how wind velocity is measured. (5) How are winds classified? (6) Read Moore, Chapter X.

5. State kind of pressure over north Pacific in (a) summer and (b) winter. (2) Give direction of winds upon northwest coast of North America in summer and in winter. (3) Mention effect of wind directions on rainfall and give examples.

### III. REFERENCE BOOKS.

1. Tarr's Physical Geography, Chapter XIII.
2. Dryer's Physical Geography, Chapter XXVII.
3. Realm of Nature, Chapter IX.
4. Moore's Descriptive Meteorology, Chapters IX-XIII.
5. Story of Atmosphere, Chapters IX-XIII.
6. Waldo's Elementary Meteorology, Chapters VIII, IX.
7. Davis's Elementary Meteorology, Chapter X.
8. Salisbury's Physlography, Chapter XVII.

### EXERCISE XVI. WEATHER MAPS.

#### I. DIRECTIONS, ETC.

1. Draw from selected weather map, upon chart of United States, (a) "Low" over Mississippi Valley, (b) "High" over eastern and western coasts. (2) Draw isotherms in red and isobars in black. (3) Date chart. (4) Enlarge half inch, characters in explanatory notes upon weather maps. (5) Place enlarged character upon margins of charts.

2. Draw pencil lines through center of "Low" in No. 1 from east to west, north to south. (2) Note from inspection of map (a) wind directions, (b) temperature, and (c) condition of sky respecting clouds, rain, snow, etc., in middle of each quarter, beginning with southeast. (3) For sample chart see No. 19, Moore, or figure 404, Salisbury.

3. Draw as indicated in Nos. 1 and 2 "High" over Mississippi Valley, with "Lows" over eastern and western coasts. (2) Read Realm of Nature, pages 142 to 152. (3) For sample chart see Salisbury, figure 405, or Moore, chart No. 20.

4. Compare (a) barometric lines with contour lines, and (b) barometric gradient contour slope. (2) State similarity or difference. (3) Note from inspection of map comparative wind velocity in rear and front of storm. (4) Determine which way storms move through United States in temperate belt. (5) Waldo, page 223, or Moore, charts Nos. 32 and 33.

5. Draw in proper colors set of "Storm signals," (a) size, 4 centimeters square, black center, one-third width; (b) pennants, 8.5 centimeters long and 4 centimeters wide. (2) Draw in proper colors set of "Weather signals." (a) size, 4 centimeters square, (b) label each signal, and (c) state in which quarter of "storm" each signal should appear. (3) See United States signal cards or flags.

#### II. WRITTEN REVIEW.

1. Give wind direction and weather conditions in (a) eastern, (b) western, and (c) central part of United States as per chart No. 1. (2) State conditions

of (a) barometer, (b) thermometer, (c) sky, and (d) wind directions before coming of low pressure storm from west. (3) State direction of forward movement.

2. Give direction and weather conditions in (a) eastern, (b) western, and (c) central part of United States as per chart No. 2. (2) State conditions of (a) barometer, (b) thermometer, (c) sky, and (d) wind directions before coming of anticyclone or high-pressure storm from the west.

3. Determine barometric gradient in (a) front and (b) rear of "low" in chart No. 1. (2) State which gradient is usually steeper, "front" or "rear." (3) Mention relation between gradient and wind velocity. (4) Read Salisbury, page 396. (5) How does distance between isobars indicate velocity of wind? (6) Read Waldo, page 100, Realm of Nature, 116.

4. State in what ways (a) wind directions, (b) wind velocity, (c) barometric gradients are shown upon weather maps. (2) State how (a) temperature, (b) pressure, (c) condition of sky are indicated upon weather map. (3) Examine charts.

5. Describe proper "storm signal" to be used in each quarter of storm. (2) What kind of signal is used in case of hurricane? (3) How are very strong winds indicated upon weather map? (4) Upon barographic sheet? (5) Name proper storm signals to be used in case of low-pressure storm coming from west.

### III. REFERENCE BOOKS.

1. Tarr's Physical Geography, Chapter XIII.
2. Dryer's Physical Geography, Chapter XXVII.
3. Realm of Nature, Chapter IX.
4. Salisbury's Physiography, Chapter XVII.
5. Story of Atmosphere, Chapters I, X, XII.
6. Waldo's Elementary Meteorology, Chapters VIII, IX.
7. Davis's Elementary Meteorology, Chapter X.
8. Moore's Descriptive Meteorology, Chapter XIII.

### EXERCISE XVII. SPECIAL WINDS AND STORMS.

#### I. DIRECTIONS, ETC.

1. Prepare explanation for (a) land breezes and (b) sea breezes. (2) Note (a) causes, (b) time of occurrences, and (c) direction of winds. (3) Read Realm of Nature, pages 122 to 126, and enlarge upon upper and lower halves of page, figures 25 and 26. (4) Read Davis, pages 134, 313; Waldo, page 262, or Moore, page 182, and prepare summary.

2. Draw upon upper and lower halves of page two maps of India, one for summer and one for winter. (2) Indicate upon maps (a) latitude, (b) mountains, (c) rivers, (d) wind directions, (e) rainfall in colors, (f) pressure lines, and (g) words "High" and "Low" in proper places. (3) Read Tarr, pages 257 and 284; Davis, page 123, or Moore, page 180. (4) Note (a) wind direction and (b) rainfall during (a) summer, (b) winter.

3. Determine what is meant by mountain and valley winds. (2) Prepare explanation for (a) causes and (b) time and place of occurrence, and (c) character of (a) Foehn, (b) Chinook, (c) Sirocco, and (d) Mistral. (3) Read Davis, page 137; Waldo, page 262, or Moore, page 184.

4. Read Waldo, page 287, or Moore, page 223, and prepare summary of what is said concerning cold and hot waves. (2) Read Moore, pages 185 to 188, and inspect charts Nos. 24, 25.

5. Insert upon upper and lower parts of page vertical and cross sections of hurricane, figures 426 and 428, Tarr. (2) Draw through center of figure two straight lines at right angles. (3) Note direction of spiral whirl in upper, center, and lower parts of figure 426. (4) Note direction of forward movement of storm. (5) What is meant by front and rear of storm? (6) Notice how storm is represented upon weather map in figure 427, also by barographic line, figure 297, Dryer.

## **II. WRITTEN REVIEW.**

1. State comparative temperature over land and water during day and night, summer and winter. (2) What effect has heat upon atmospheric pressure? (3) What causes land and sea breezes? (4) Mention some places where land and sea breezes are strong. (5) State about what time of day each wind occurs.

2. In what wind belt is India? (2) Why is India not desert like Arabia? (3) Explain what causes wind to blow toward and away from India periodically. (4) Account for periodical floods and droughts in India. (5) Describe in separate paragraphs (a) summer and (b) winter monsoon in India.

3. What causes mountain and valley wind? (2) Mention some effects of such winds upon temperature and life. (3) Describe Foehn or Chinook winds as to cause, time of occurrence, and character. (4) Read Davis, page 234, or Moore, page 186.

4. Give cause and character of some hot winds. (2) Do same in relation to cold winds. (3) State effect of such winds upon life. (4) Read Davis, pages 230-233.

5. Mention important features of hurricanes. (2) Explain why such storms are so destructive to buildings. (3) What places are considered safest during tornadoes? (4) When and where do hurricanes or typhoons occur frequently? (5) Describe ordinary (a) whirlwind, (b) hurricane, (c) typhoon, or (d) tornado. (6) Read Dryer, pages 318 to 323. (7) State how violent storms are indicated by (a) barograph, (b) thermograph, (c) wind directions, and (d) conditions of sky. (8) How are such storms indicated upon weather map? By storm signals?

## **III. REFERENCE BOOKS.**

1. Tarr's Physical Geography, Chapter XIII.
2. Dryer's Physical Geography, Chapter XXVII.
3. Realm of Nature, Chapter IX.
4. Salisbury's Physiography, Chapter XVI.
5. Davis's Elementary Meteorology, Chapter VII.
6. Waldo's Elementary Meteorology, Chapter X.
7. Story of Atmosphere, Chapter IX.
8. Moore's Descriptive Meteorology, Chapters X-XIII.

## **EXERCISE XVIII. ATMOSPHERIC MOISTURE.**

### **I. DIRECTIONS, ETC.**

1. Record upon properly ruled paper condition of sky daily by using symbols upon United States weather maps. (2) Record kinds of clouds by using abbreviations shown upon United States cloud charts. (3) Examine charts and maps. (4) Read what is said in references regarding atmospheric moisture. (5) Insert upon properly ruled paper table, page 280, Dryer. (6) Note relation between saturated air and temperature.

2. Note what is said regarding (a) relative and (b) absolute humidity. (2) Note also effect of increase or decrease of temperature upon relative humidity. (3) Observe relative weight of dry air and water vapor. (4) Note change in volume from water to water vapor. (5) Read *Realm of Nature*, pages 42, 102, 104.

3. Draw from observation of instrument or pages 401-402, *Dryer*, hygrometer. (2) Determine by use of hygrometer and table, page 408, *Dryer*, relative humidity of room daily. (3) Explain drawing by means of letters. (4) Observe readings of each thermometer. (5) Determine which is lower. (6) Prepare explanation for difference. (7) See Exercise VII for scale for thermometers.

4. Make drawing of experiment to illustrate (a) evaporation and (b) condensation of moisture. (2) Letter different parts of drawing for explanation. (3) Note effect (a) of heat upon evaporation and (b) of cold upon condensation. (4) Insert table, page 147, *Davis*, and prepare explanation.

5. Observe from experiment what it is that causes condensation. (2) Enumerate four processes of cooling as given in *Dryer*, page 282. (3) State clearly substance of each paragraph separately. (4) Read carefully Chapter XII, *Moore's Descriptive Meteorology*.

## II. WRITTEN REVIEW.

1. Explain table in No. 1. (2) How much does water expand before it becomes water vapor? (3) What is cause of expansion? (4) Explain what is meant by saturated air. (5) Name five conditions favorable for evaporation. (6) Name five benefits arising from evaporation of moisture.

2. Define and give examples of (a) absolute humidity, (b) relative humidity, and (c) point of saturation. (2) State effects of (a) increase or (b) decrease of temperature upon humidity. (3) Give examples to illustrate meaning. (4) What is meant by "damp air"?

3. Describe in full hygrometer. (2) State how (a) relative humidity and (b) dew points are determined by hygrometer and table. (3) Explain why reading upon one thermometer is less than reading upon other thermometer. (4) State effect of evaporation upon temperature. (5) Explain why it is cooler after rains in summer. (6) Why are summers in western Washington cooler than summers in eastern Washington?

4. Explain experiment in No. 4. (2) Mention some favorable condition for condensation. (3) Substitute blades of grass for cold-jar experiment, and explain formation of dew. (4) Substitute cold dust particles for cold jar, and explain formation of fog and clouds. (5) Read *Moore*, pages 204, 205.

5. Mention four ways through which condensation is produced. (2) Explain formation of fogs off shore. (3) Explain formation of clouds about mountain tops. (4) Why do clouds accumulate with south winds and disperse with north winds?

## III. REFERENCE BOOKS.

1. *Dryer's Physical Geography*, Chapter XXIII.
2. *Sigsbee's Cloud Forms*.
3. *Moore's Descriptive Meteorology*, Chapters VI, VII.
4. *Tarr's Physical Geography*, Chapter XII.
5. *Waldo's Elementary Meteorology*, Chapter V.
6. *Harrington's "Weather,"* Chapters X, XI.
7. *Salisbury's Physlography*, Chapter XIV.
8. *Davis's Elementary Meteorology*, Chapter VIII.

**EXERCISE XIX. MOISTURE (Continued).****I. DIRECTIONS, ETC.**

1. Classify cloud forms. (2) See Government charts and read references to clouds. (3) Note form, height, etc., of each class. (4) Insert mean height in table, page 179, Davis, or page 111, Story of Atmosphere. (5) Note from table whether clouds are higher in summer or winter. (6) State reason for observation.

2. Prepare in separate paragraphs short explanations with examples to illustrate following ways of causing rain: (a) Thunder storms, (b) cyclones, (c) doldrums, (d) volcanoes, (e) mountains, (f) intermingling winds, (g) land and sea breezes, (h) southerly winds. (2) Read references to each topic, also rainfall.

3. Read Dryer, Chapter XXVIII. (2) Observe and prepare to explain cause and distribution of rainfall as represented upon summer and winter charts. (3) Insert four general laws governing distribution of rainfall as given on page 333, Dryer.

4. Reproduce from books or charts four snow crystals 2 inches in diameter. (2) Note number of sides to crystals. (3) Mention condition most favorable to formation of snow. (4) Read Waldo, page 159, or Realm of Nature, page 113.

5. Record daily (a) kinds of clouds observed, (b) weather conditions, and (c) wind directions. (2) Note daily relation between (a) kind of clouds, (b) kind of weather and direction of winds. (3) Notice conditions of barometer daily.

**II. WRITTEN REVIEW.**

1. Enumerate in separate paragraphs chief features of each primary class of clouds. (2) Mention kind of weather usually associated with each class. (3) Read Realm of Nature, page 111, or Waldo, page 129.

2. Note general direction of mountain systems and prevailing winds upon each continent. (2) Compare height of rain-bearing clouds with height of mountains. (3) Locate rain and rainless belts. (4) State causes in each case. (5) What causes rain to fall upon oceans and plains?

3. Explain why clouds and rain should occur in front and center of low-pressure storms while sky is clear and cold in rear. (2) See Davis, page 228, and refer to diagrams of storms. (3) What effect has condensation of water vapor upon temperature? (4) Explain effect of rainfall upon temperature of western Washington.

4. Mention weather conditions favorable to formation of frost, ice, or snow. (2) Name some advantages of snow or ice as compared with rain. (3) Mention and give examples of advantages of snowfall to (a) water supply, (b) irrigation, (c) temperature, and (d) agriculture.

5. Mention kind of clouds that usually accompany low barometer and southwest winds. (2) What kind of weather do such clouds indicate? (3) Windy weather is indicated by what kind of cloud forms? (4) Cold weather with high barometer is usually accompanied by what kind of clouds? (5) Mention some uses of clouds.

**III. REFERENCE BOOKS.**

1. Dryer's Physical Geography, Chapter XXIII.
2. Tarr's Physical Geography, Chapter XII.
3. Story of Atmosphere, Chapters VII, VIII.
4. Moore's Descriptive Meteorology, Chapters XI, XII.
5. Waldo's Elementary Meteorology, Chapter V.
6. Davis's Elementary Meteorology, Chapter VIII.
7. Harrington's "Weather," Chapters X, XI, XII.
8. Salisbury's Physiography, Chapter XIV.

**EXERCISE XX. THE OCEAN.****I. DIRECTIONS, ETC.**

1. Draw in red upon chart of world thermal lines showing temperature of surface water. (2) Read Tarr, pages 182-184, and see figure 320, Tarr, or page 253, Dryer. (3) Insert and explain beneath, table, page 254, Dryer. (4) Note from chart and table where temperature is greatest and where least. (5) Prepare explanation.

2. Give short description of (a) wind waves and (b) storm waves. (2) Include in description (a) cause, (b) size, and (c) effect of waves upon shore line. (3) Determine what is meant by (a) crest, (b) trough, (c) length, and (d) height of waves. (4) Use delta table for demonstration. (5) Note relation between size of waves and angle of wind. (6) Velocity of wind and force of waves.

3. Draw four diagrams showing relative position of (a) earth, (b) moon, and (c) sun at (a) neap and (b) spring tides. (2) See Appendix E, Tarr, or Dryer, page 263. (3) Explain each diagram by letters. (4) Indicate sun's gravity by red lines. (5) Note difference in height of tide at (a) new, (b) full, and (c) quarter moon, and prepare explanation. (6) See diagrams, page 511, Salisbury.

4. Draw upon chart of world cotidal lines in each ocean. (2) See Realm of Nature, page 258. (3) Note directions of tidal waves in each ocean. (4) Observe effect of continents upon direction and height of tidal waves.

5. Place upon chart of world ocean currents, warm in red and cold in black, with names in proper places. (2) See Dryer, page 257, or Tarr, page 194. (3) Note directions of drift of (a) warm and (b) cold currents. (4) Which way would currents flow if earth stood still? (5) If earth rotated from east to west? (6) Compare temperatures near eastern and western coasts of continents. (7) See thermal charts, and read Moore, page 266.

**II. WRITTEN REVIEW.**

1. State where sea water is (a) warmest and where (b) coldest. (2) Give reasons for each statement. (3) How do thermal lines upon ocean compare with thermal lines upon land? (4) Compare temperature of land with temperature of water in (a) summer and in (b) winter. (5) State how depth of water affects temperature. (6) See chart and table, and read Moore, pages 83-86.

2. Explain relation between (a) velocity of wind and force of waves, (b) angle of wind and size of waves. (2) Explain what is meant by (a) crest, (b) trough, (c) length, and (d) height of waves. (3) What is meant by (a) breakers and (b) undertow? (4) What effect have waves upon shore lines? Upon evaporation?

3. How are tides produced? (2) State what is meant by "tidal waves." (3) Give direction of tidal currents in north, south, and middle of each ocean. (4) Show how contents and shore lines affect (a) direction and (b) height of tidal water. (5) Explain how time of tides is determined. (6) Account for difference in time of tides in same and in different ports.

4. What causes ocean currents? (2) Of what importance are ocean currents to man? (3) Describe two currents, one warm and the other cold, in each ocean. (4) Give general effect of each current upon climate. (5) State effect of earth's rotation and continental masses upon direction of currents. (6) What effect have winds upon currents?

5. Record daily upon properly ruled paper conditions of tides in Tacoma for month, together with phases of moon. (2) See daily papers or tide tables, and observe tides daily in bay. (3) At what phase of moon is tide highest? (4) When is difference between high and low tides least? (5) How many feet difference between extreme high and low tides in Tacoma? (6) Show how tides assist in commerce.

**III. REFERENCE BOOKS.**

1. Tarr's Physical Geography, Chapter X.
2. Dryer's Physical Geography, Chapters XIX-XXI.
3. Salisbury's Physiography, Chapter XX.
4. Pilot Charts, Tide Tables.
5. Realm of Nature, Chapters X, XI.
6. Maury's Geography of Sea.
7. Shaler's Sea and Land.
8. Newcomb's Astronomy.















U. S. DEPARTMENT OF AGRICULTURE,  
WEATHER BUREAU. .

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THE RELATION BETWEEN THE PRECIPITATION  
OVER THE WATERSHED OF THE OHIO RIVER  
ABOVE AND THE STREAM-FLOW  
AT CINCINNATI.

BY

J. WARREN SMITH,  
PROFESSOR OF METEOROLOGY.

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Prepared under direction of WILLIS L. MOORE, Chief U. S. Weather Bureau.

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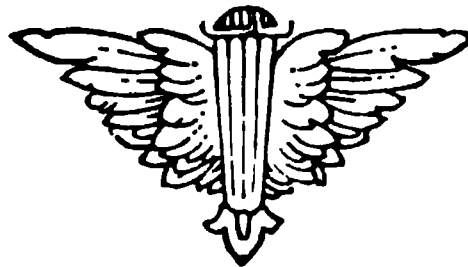
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## LETTER OF TRANSMITTAL.

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UNITED STATES DEPARTMENT OF AGRICULTURE,  
WEATHER BUREAU, OFFICE OF THE CHIEF,  
*Washington, D. C., September 20, 1911.*

The SECRETARY OF AGRICULTURE,  
*Washington, D. C.*

SIR: I have the honor to transmit herewith a paper by Prof. J. Warren Smith, of the Weather Bureau, on the Stream Flow of the Ohio River at Cincinnati and Precipitation, and to recommend its publication as a Weather Bureau bulletin, the edition to consist of 2,500 copies.

Very respectfully,

WILLIS L. MOORE,  
*Chief United States Weather Bureau.*

Approved.

JAMES WILSON,  
*Secretary of Agriculture.*



# STREAM-FLOW OF THE OHIO RIVER AT CINCINNATI AND PRECIPITATION IN THE WATERSHED ABOVE CINCINNATI.

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## INTRODUCTION.

In the following paper the relation between the precipitation over the Ohio watershed above Cincinnati and the stream-flow in the Ohio River at Cincinnati is discussed.

The period covered is for 50 years, from 1861 to 1910, inclusive. The data are tabulated for each month of each year, for each month of 10-year and 25-year groups of years, and for combinations of months for each year of the entire period.

The precipitation data considered were obtained from seven stations in the Ohio River watershed above Cincinnati, the period of observations covering the 50 years from 1861 to 1910, inclusive. The data are complete for the 50 years at Cincinnati, Marietta, and Portsmouth, Ohio. At Lexington, Ky., the records extend from 1861 to 1876 and from 1887 to 1910, all inclusive, while from 1882 to 1886, inclusive, the records at Frankfort, Ky., were used. The record at Pittsburgh, Pa., extends from 1861 to 1866, and from 1872 to 1910, all inclusive, while from 1867 to 1871, inclusive, data from Canonsburg, Pa., were used. The data at Westerville, Ohio, were complete from 1861 to 1901, inclusive, while from 1902 to 1910, inclusive, those for the Ohio State University were used. In the place of North Lewisburg, Ohio, the data for Urbana, Ohio, were used for the years 1909 and 1910. In each instance where data from two stations were used, the places were not far apart, and there is probably no great difference in the precipitation.

It is unfortunate that there are no stations with long records in West Virginia or at other points south of the Ohio River. It is quite probable that the means obtained from the seven stations used do not always give the true average precipitation for the Ohio watershed above Cincinnati. Still, it was thought better to use the same stations running through the 50-year period than to consider data from other sources.

Chart No. 1 indicates the locations of the stations.

For the stream-flow data, instead of considering the average height of the water, we have tabulated the total number of days in each month when the river was between each 10-foot stage.

Inasmuch as navigation is satisfactory in the Ohio when the river at Cincinnati is between 10 and 40 feet, we have considered the low-water days as those below 10 feet, and the high-water days as those above 40 feet.

The flood stage is 50 feet at Cincinnati, but there is more or less trouble in navigating the stream when the river is above 40 feet because of strong currents, swirls, débris, and, in its season, ice.

The work of tabulation has been great, and we have tried to group the data in every possible way to show the relation of the factors under consideration. An effort has been made to make the study exhaustive, plain, and convincing.

It seems to the writer that the statements made in the conclusions following are proven beyond dispute, and that the question of increasing flood conditions and increasing low-water periods is fairly settled in the negative, so far as our available stream-flow data can settle it.

### CONCLUSIONS.

1. River stages at Cincinnati depend upon the precipitation over the *whole* watershed above that city.

2. There has been a very slight decrease in flood days in recent years, with the same rainfall.

3. The same amount of rainfall causes a better flow of water in the river during the low-water period than formerly. The number of low-water days was 14 per cent less during the past 25 years than during the preceding 25, calculating for the same rainfall. During the 10 years ending with 1910 the tendency for low water, with an equivalent rainfall, was not so great as for any preceding 10-year period for the past 50 years.

4. Floods do not occur at Cincinnati during February and March unless the precipitation for these months is in excess of the normal, except on *very* rare occasions. The number of flood days increase most rapidly when the precipitation during these months is about 3 inches above the normal or about one-half more than the normal.

### EXPLANATION AND DISCUSSION OF TABLES.

#### TABLE No. 1.

In this table there is given for each month of each year from 1861 to 1910, inclusive, the total number of days that the river at Cincinnati, Ohio, was below 5 feet, between 5 and 5.9 feet, 10 and 19.9 feet, 20 and 29.9 feet, 30 and 39.9 feet, etc., up to the highest water recorded.

These figures were obtained from the published daily river reading tables. By an inspection of the table the high and low water months can be quickly determined.

For example, in January, 1897, the water did not go above 20 feet during the month, the only January in the 50 years when this was true. On the other hand, the river reading was at no time below 20 feet in January, 1870, 1882, 1889, 1891, and 1907. The river has been above 60 feet on only 6 days in January, and this in 1907.

There are some interesting periodicities or combinations indicated. For example, there seemed to be increasing flood conditions in February, 1881 to 1884, and again from February, 1888 to 1891, but in the succeeding years the river was back to below normal height.

The river did not go above 20 feet in June from 1871 to 1879, inclusive. September seems to be a month of extremes; on a few years the river has not gone above 5 feet during the entire month, and in 2 cases the readings were all above 10 feet.

TABLE 1.—Number of days during each month and year when the river reading at Cincinnati, Ohio, was between the heights indicated, 1861 to 1910.

Years.	0 to 4.9 feet.	5 to 9.9 feet.	10 to 19.9 feet.	20 to 29.9 feet.	30 to 39.9 feet.	40 to 49.9 feet.	50 to 59.9 feet.	60 to 69.9 feet.	70 to 79.9 feet.
<b>JANUARY.</b>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1861			15	8	6	2			
1862			12	6	3	4	6		
1863			15	4	11	1			
1864		6	16	9					
1865			8	14	9				
1866			9	14	8				
1867			26	5					
1868			16	6	6	3			
1869			7	9	15				
1870				15	6	4	6		
1871		14	10	4	3				
1872		11	15	5					
1873			10	17	4				
1874			5	10	10	6			
1875		5	18	4	4				
1876			7	9	4	10	1		
1877			13	4	5	4	5		
1878		4	10	17					
1879			13	6	12				
1880			1	19	8	3			
1881		5	8	13	5				
1882				2	6	23			
1883			20	9	2				
1884			10	13	8				
1885			11	12	3	5			
1886			9	17	5				
1887			17	9	2	3			
1888		4	12	9	6				
1889				26	5				
1890			2	9	14	6			
1891				17	8	6			
1892			12	13	4	2			
1893		5	24	2					
1894			29	2					
1895		5	1	10	10	5			
1896		11	12	8					
1897		1	30						
1898			9		6	11	5		
1899			2	12	9	8			
1900		7	9	10	5				
1901		4	20	7					
1902		6	14	4	5	2			
1903			12	13	6				
1904			21	4	2	4			
1905		1	25	5					
1906			5	17	9				
1907				3	9	8	5	6	
1908			14	17					
1909		1	21	9					
1910		2	5	7	9	8			

TABLE 1.—Number of days during each month and year when the river reading at Cincinnati, Ohio, was between the heights indicated, 1861 to 1910—Continued.

Years.	0 to 4.9 feet.	5 to 9.9 feet.	10 to 19.9 feet.	20 to 29.9 feet.	30 to 39.9 feet.	40 to 49.9 feet.	50 to 59.9 feet.	60 to 69.9 feet.	70 to 79.9 feet.
<b>FEBRUARY.</b>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1861			7	11	10				
1862			3	4	11	10			
1863			1	10	16	1			
1864		7	11	11					
1865			12	13	1	2			
1866			13	11	4				
1867			2	5	6	8	7		
1868		3	23	3					
1869			4	21	3				
1870			10	10	8				
1871			7	19	2				
1872		9	17	3					
1873			6	7	12	3			
1874			7	10	6	5			
1875		4	16	7	1				
1876			3	7	9	10			
1877		1	18	6	3				
1878			3	23	2				
1879			4	17	5	2			
1880			12	7	3	3	4		
1881			7	5	7	7	2		
1882				4	4	11	9		
1883				5	5	2	9	7	
1884				2	2	6	6	11	2
1885		4	17	7					
1886			5	14	8	1			
1887						18	10		
1888		3	8	18					
1889			12	9	7				
1890				3	12	10	3		
1891					2	18	8		
1892			7	22					
1893				4	10	6	8		
1894			5	12	11				
1895			28						
1896			11	13	5				
1897			4	5	7	6	4	2	
1898			9	7	12				
1899			9	7	12				
1900			8	12	8				
1901		4	23	1					
1902		8	9	5	4	2			
1903				4	10	14			
1904			16	11	2				
1905		7	5	12	4				
1906		3	21	4					
1907			11	14	3				
1908			3	12	5	7	2		
1909			9	5	9	1	4		
1910			7	12	8	1			
<b>MARCH.</b>									
1861			10	21					
1862				7	18	6			
1863				5	23	3			
1864			13	18					
1865				2	10	14	5		
1866			2	11	18				
1867				3	9	7	12		
1868			2	9	10	10			
1869			7	14	8	2			
1870				26	3	2			
1871				26	5				
1872		5	24	2					
1873			16	11	4				
1874			7	16	8				
1875				5	21	5			
1876			11	11	8	1			
1877		1	7	7	13	3			
1878			7	18	6				
1879				11	20				
1880				15	9	7			
1881				26	5				
1882				10	15	6			
1883				13	18				
1884			3	5	8	15			
1885		4	19	8					

TABLE 1.—Number of days during each month and year when the river reading at Cincinnati, Ohio, was between the heights indicated, 1861 to 1910—Continued.

Years.	0 to 4.9 feet.	5 to 9.9 feet.	10 to 19.9 feet.	20 to 29.9 feet.	30 to 39.9 feet.	40 to 49.9 feet.	50 to 59.9 feet.	60 to 69.9 feet.	70 to 79.9 feet.
<b>MARCH—continued.</b>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1886.....			18	7	5	1			
1887.....			12	4	8	4	3		
1888.....			13	12	6				
1889.....			14	17					
1890.....				3	4	12	12		
1891.....					21	10			
1892.....			4	19	8				
1893.....			2	22	7				
1894.....			8	23					
1895.....			3	17	11				
1896.....			17	3	11				
1897.....					17	12	2		
1898.....			13	6	2	3	5	2	
1899.....				5	13	6	7		
1900.....			1	16	14				
1901.....		7	2	15	7				
1902.....			4	4	8	11	4		
1903.....				3	9	11	8		
1904.....			1	11	5	14			
1905.....			3	12	5	11			
1906.....			6	13	11	1			
1907.....				14	2	4	7	4	
1908.....				2	10	13	6		
1909.....			6	8	9	6	2		
1910.....			12	4	3	9	3		
<b>APRIL.</b>									
1861.....			5	12	6	7			
1862.....				9	6	9	6		
1863.....			12	15	3				
1864.....			1	22	7				
1865.....			5	8	11	6			
1866.....			2	19	9				
1867.....				25	5				
1868.....			4	12	12	2			
1869.....				20	4	6			
1870.....				10	7	13			
1871.....			18	12					
1872.....		4	8	3	10	5			
1873.....			4	11	15				
1874.....			4	6	14	6			
1875.....			11	12	7				
1876.....			6	19	4	1			
1877.....			9	17	4				
1878.....			28	2					
1879.....			15	10	5				
1880.....			13	12	2	3			
1881.....				18	9	3			
1882.....			22	8					
1883.....				8	13	9			
1884.....			9	13	8				
1885.....		1	5	14	10				
1886.....			8	4	2	4	12		
1887.....			17	4	4	5			
1888.....			11	12	7				
1889.....			22	8					
1890.....			1	12	16	1			
1891.....			5	8	11	6			
1892.....				16	8	6			
1893.....			5	17	7	1			
1894.....			15	15					
1895.....			7	14	9				
1896.....			13	8	3	6			
1897.....			5	14	11				
1898.....			6	17	2	2	3		
1899.....			10	12	4	2	2		
1900.....			23	7					
1901.....				8	12	2	8		
1902.....			8	14	5	3			
1903.....				11	14	5			
1904.....			11	8	6	5			
1905.....			18	11	1				
1906.....			6	15	3	5	1		
1907.....				29	1				
1908.....				10	11	5	4		
1909.....			4	21	5				
1910.....			24	6					



TABLE 1.—Number of days during each month and year when the river reading at Cincinnati, Ohio, was between the heights indicated, 1861 to 1910—Continued.

Years.	0 to 4.9 feet.	5 to 9.9 feet.	10 to 19.9 feet.	20 to 29.9 feet.	30 to 39.9 feet.	40 to 49.9 feet.	50 to 59.9 feet.	60 to 69.9 feet.	70 to 79.9 feet.
<b>MAY.</b>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1861.			10	14	7				
1862.			22	7	2				
1863.		4	16	11					
1864.			15	10	6				
1865.			5	9	9	6	2		
1866.		5	22	4					
1867.			11	17	3				
1868.			6	10	13	2			
1869.			12	14	5				
1870.			28	3					
1871.		3	11	10	6	1			
1872.		8	23						
1873.			10	12	9				
1874.		7	12	5	3	4			
1875.		6	21	4					
1876.			23	8					
1877.			21	10					
1878.			9	21	1				
1879.		10	21						
1880.		12	11	4	2	2			
1881.		2	21	8					
1882.			1	13	13	4			
1883.			17	14					
1884.			25	6					
1885.			30	1					
1886.			17	6	8				
1887.		3	10	14	4				
1888.		5	26						
1889.			25	6					
1890.				10	14	7			
1891.		20	11						
1892.			5	20	6				
1893.			1	10	9	9	2		
1894.		2	22	4	3				
1895.			31						
1896.		10	21						
1897.			11	16	4				
1898.			2	29					
1899.			20	11					
1900.		6	25						
1901.			12	9	7	2	1		
1902.		4	27						
1903.		12	16	3					
1904.			17	9	5				
1905.			15	7	3	6			
1906.		7	22	2					
1907.			10	20	1				
1908.				19	6	6			
1909.			9	11	4	7			
1910.			19	12					
<b>JUNE.</b>									
1861.		12	14	4					
1862.			24	6					
1863.	6	24							
1864.		11	19						
1865.			28	2					
1866.	2	28							
1867.		1	21	8					
1868.		3	20	7					
1869.			18	12					
1870.		2	23	5					
1871.		27	3						
1872.		12	18						
1873.		23	7						
1874.		30							
1875.		4	26						
1876.		15	15						
1877.		10	20						
1878.		9	21						
1879.		25	5						
1880.		5	20	5					
1881.		8	15	4	3				
1882.			10	10	10				
1883.			13	14	3				
1884.			8	22					
1885.		4	22	4					

TABLE 1.—Number of days during each month and year when the river reading at Cincinnati, Ohio, was between the heights indicated, 1861 to 1910—Continued.

Years.	0 to 4.9 feet.	5 to 9.9 feet.	10 to 19.9 feet.	20 to 29.9 feet.	30 to 39.9 feet.	40 to 49.9 feet.	50 to 59.9 feet.	60 to 69.9 feet.	70 to 79.9 feet.
<b>JUNE—continued.</b>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1886		2	24	4					
1887		9	15	6					
1888		19	11						
1889			5	20	5				
1890			24	4	2				
1891			18	12					
1892			13	13	4				
1893			26	4					
1894		11	18	1					
1895	5	24	1						
1896		6	21	3					
1897		6	23	1					
1898		9	21						
1899			30						
1900		16	14						
1901			4	15	9	2			
1902		15	14	1					
1903			30						
1904		4	16	10					
1905			24	6					
1906		3	27						
1907			7	13	7	3			
1908		4	26						
1909			16	14					
1910			11	17	2				
<b>JULY.</b>									
1861		31							
1862		8	23						
1863		24	7						
1864	18	13							
1865		9	21	1					
1866		18	10	3					
1867		28	3						
1868		31							
1869			16	15					
1870		17	14						
1871		31							
1872		11	20						
1873		6	23	2					
1874	10	19	2						
1875			13	4	14				
1876		8	23						
1877		11	20						
1878		22	9						
1879	8	23							
1880		14	17						
1881		25	6						
1882		2	18	11					
1883		2	29						
1884	1	17	13						
1885	2	27	2						
1886		6	21	4					
1887	8	23							
1888		12	12	5	2				
1889			21	10					
1890		18	13						
1891		3	28						
1892		10	21						
1893		21	10						
1894	15	16							
1895	4	24	3						
1896		1	14	10	4	2			
1897		6	19	6					
1898		25	6						
1899		26	5						
1900		22	9						
1901		4	25	2					
1902			16	15					
1903		2	29						
1904		8	19	4					
1905			28	3					
1906		17	14						
1907			20	11					
1908		19	12						
1909		9	21	1					
1910		5	20	6					

TABLE 1.—Number of days during each month and year when the river reading at Cincinnati, Ohio, was between the heights indicated, 1861 to 1910—Continued.

Years.	0 to 4.9 feet.	5 to 9.9 feet.	10 to 19.9 feet.	20 to 29.9 feet.	30 to 39.9 feet.	40 to 49.9 feet.	50 to 59.9 feet.	60 to 69.9 feet.	70 to 79.9 feet.
<b>AUGUST.</b>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1861		11	20						
1862	15	16							
1863	5	26							
1864	18	3	10						
1865		13	18						
1866	2	20	9						
1867	1	30							
1868		21	10						
1869		22	9						
1870		9	22						
1871	12	19							
1872		23	8						
1873		12	19						
1874		24	7						
1875		1	16	3	2	4	5		
1876		18	13						
1877	17	14							
1878		17	14						
1879		18	13						
1880		21	10						
1881	13	18							
1882		11	19	1					
1883	1	20	10						
1884	9	18	4						
1885		3	28						
1886		14	17						
1887	19	12							
1888		20	5	3	3				
1889		10	21						
1890		21	8	2					
1891		12	19						
1892		28	3						
1893	16	15							
1894	30	1							
1895		31							
1896			21	3	5	2			
1897		20	11						
1898			18	8	5				
1899	5	19	7						
1900	2	24	5						
1901		14	17						
1902		18	13						
1903		31							
1904		31							
1905		3	28						
1906		5	24	2					
1907		5	22	4					
1908		24	7						
1909		19	12						
1910	17	14							
<b>SEPTEMBER.</b>									
1861		22	7	1					
1862	30								
1863	30								
1864		3	27						
1865		8	18	4					
1866		7	12	4	5	2			
1867	22	8							
1868		10	7	8	3	2			
1869		19	7	4					
1870	6	20	4						
1871	15	15							
1872	14	16							
1873	11	14	5						
1874	22	8							
1875	18	12							
1876		12	6	9	3				
1877	7	23							
1878		18	5	3	4				
1879	8	16	6						
1880	5	25							
1881	24	6							
1882			30						
1883	29	1							
1884	30								
1885		12	18						

TABLE 1.—Number of days during each month and year when the river reading at Cincinnati, Ohio, was between the heights indicated, 1861 to 1910—Continued.

Years.	0 to 4.9 feet.	5 to 9.9 feet.	10 to 19.9 feet.	20 to 29.9 feet.	30 to 39.9 feet.	40 to 49.9 feet.	50 to 59.9 feet.	60 to 69.9 feet.	70 to 79.9 feet.
<b>SEPTEMBER—continued.</b>									
1886	11	19							
1887	30								
1888		2	24	4					
1889		28	2						
1890			15	10	5				
1891		17	13						
1892	3	27							
1893	5	20	5						
1894	24	2	4						
1895	16	14							
1896		30							
1897	17	13							
1898		29	1						
1899	14	16							
1900	17	13							
1901		12	18						
1902	27	3							
1903		22	8						
1904	18	12							
1905		14	16						
1906		16	14						
1907		1	29						
1908	25	5							
1909		30							
1910	3	26	1						
<b>OCTOBER.</b>									
1861			17	9	3	2			
1862	31								
1863	25	6							
1864		9	18	4					
1865		25	6						
1866		5	17	6	3				
1867	31								
1868		20	7	3	1				
1869		24	7						
1870	6	25							
1871	31								
1872	24	7							
1873	23	1	3	4					
1874	16	15							
1875		31							
1876	1	16	14						
1877	15	16							
1878	16	10	5						
1879	31								
1880	20	11							
1881	26	5							
1882		21	10						
1883		24	7						
1884	28	3							
1885	11	6	14						
1886	17	14							
1887	31								
1888		11	5	11	4				
1889		24	7						
1890			15	12	4				
1891	18	13							
1892	28	3							
1893		15	16						
1894	23	8							
1895	31								
1896		2	25	4					
1897	31								
1898	4	18	4	5					
1899	31								
1900	27	3	1						
1901	3	28							
1902	3	24	4						
1903	10	17	4						
1904	31								
1905		19	11	1					
1906			31						
1907		18	13						
1908	27	4							
1909	15	15	1						
1910	7	17	7						

TABLE 1.—*Number of days during each month and year when the river reading at Cincinnati, Ohio, was between the heights indicated, 1861 to 1910—Continued.*

Years.	0 to 4.9 feet.	5 to 9.9 feet.	10 to 19.9 feet.	20 to 29.9 feet.	30 to 39.9 feet.	40 to 49.9 feet.	50 to 59.9 feet.	60 to 69.9 feet.	70 to 79.9 feet.
<b>NOVEMBER.</b>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1861			13	16	1				
1862	19	8	3						
1863		22	8						
1864		2	8	20					
1865		16	14						
1866		1	12	17					
1867	11	19							
1868		5	25						
1869		23	7						
1870		25	5						
1871	20	4	6						
1872		17	13						
1873		4	18	8					
1874	26	1	3						
1875		6	19	5					
1876		8	22						
1877		16	10	1	3				
1878		4	21	3	2				
1879	20	5	5						
1880		14	16						
1881		6	18	6					
1882		39							
1883			26	4					
1884	24	6							
1885			29	1					
1886	13	4	5	7	1				
1887	28	2							
1888			3	17	10				
1889			11	10	9				
1890			8	18	4				
1891	2	19	5	4					
1892	11	19							
1893		18	12						
1894	7	23							
1895	26	4							
1896		1	27	2					
1897	8	11	11						
1898			22	8					
1899	8	22							
1900	6	17	3	1	3				
1901	20	9	1						
1902	3	24	3						
1903	11	12	7						
1904	25	5							
1905			29	1					
1906		8	13	5	4				
1907		2	17	11					
1908	21	9							
1909		29	1						
1910	4	26							
<b>DECEMBER.</b>									
1861			22	5	4				
1862		23	8						
1863		6	19	6					
1864			12	11	3	5			
1865		11	10	1	7	2			
1866			3	19	9				
1867	8	7	10	4	2				
1868			18	13					
1869			8	12	11				
1870		1	30						
1871	1	24	6						
1872		19	11	1					
1873			5	14	8	4			
1874		3	27	1					
1875			10	16	1	4			
1876		7	24						
1877			25	6					
1878			6	11	11	3			
1879		7	15	2	5	2			
1880		3	18	3	7				
1881			15	1	13	2			
1882		6	25						
1883			23	1	1	6			
1884	4	8	17	2					
1885			22	8	1				

TABLE 1.—*Number of days during each month and year when the river reading at Cincinnati, Ohio, was between the heights indicated, 1861 to 1910—Continued.*

Years.	0 to 4.9 feet.	5 to 9.9 feet.	10 to 19.9 feet.	20 to 29.9 feet.	30 to 39.9 feet.	40 to 49.9 feet.	50 to 59.9 feet.	60 to 69.9 feet.	70 to 79.9 feet.
DECEMBER—continued.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.
1886			15	16					
1887	4	27							
1888			26	5					
1889			4	27					
1890			24	5	2				
1891			21	10					
1892		18	13						
1893		2	22	7					
1894		11	20						
1895	1	22	7	1					
1896			16	15					
1897			23	8					
1898			22	6	3				
1899		15	9	7					
1900		9	8	10	3	1			
1901			20	4	7				
1902			12	10	2	7			
1903		21	9	1					
1904	24	6	1						
1905			7	16	7	1			
1906			13	9	9				
1907			15	12	4				
1908	12	14	5						
1909		23	8						
1910		16	13	2					

TABLE No. 2.

This table gives the average precipitation for the watershed for each month, together with the averages for each 10 years, for each 25 years, and for the whole 50 years.

TABLE 2.—*Average precipitation in the Ohio watershed above Cincinnati, 1861 to 1910, inclusive.*

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	An- nual.
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
1861	2.5	2.0	2.3	4.5	5.0	3.5	3.5	4.5	3.3	3.6	4.0	1.2	39.9
1862	5.4	3.1	4.6	5.6	3.2	3.3	3.6	2.2	1.1	1.7	2.9	3.1	39.8
1863	6.2	3.5	3.6	2.0	2.4	2.7	2.4	2.9	2.1	3.7	2.5	3.2	37.2
1864	1.8	1.4	2.6	2.5	3.2	2.4	1.5	5.4	4.9	2.4	4.4	3.7	36.2
1865	2.6	2.4	5.0	4.5	7.3	4.3	5.8	3.8	5.9	1.5	0.9	4.6	48.8
1866	3.5	2.5	3.7	2.7	1.3	4.5	5.5	3.9	10.1	3.2	4.1	2.2	47.2
1867	2.4	5.0	5.0	2.7	4.0	3.2	3.9	2.8	0.8	3.0	2.1	4.2	39.1
1868	3.1	1.2	5.3	3.6	5.5	4.8	3.1	4.8	7.6	1.5	2.0	2.2	44.7
1869	2.9	2.9	4.2	2.9	4.6	3.9	4.5	2.2	4.0	2.0	3.6	3.1	40.8
1870	6.2	3.1	4.2	2.5	1.9	3.7	4.4	3.1	1.4	2.9	1.8	2.3	37.5
1871	2.1	2.7	2.6	2.0	2.8	3.3	3.0	4.4	1.3	1.8	2.7	2.6	31.3
1872	0.9	1.9	1.5	4.7	2.9	2.7	6.2	3.1	1.6	2.5	1.0	2.5	31.5
1873	2.5	3.6	3.1	2.9	3.8	3.5	5.7	3.8	2.3	4.5	2.1	5.0	42.8
1874	4.2	4.1	3.5	5.2	1.3	2.8	5.1	2.4	2.7	0.5	3.9	3.5	39.2
1875	1.7	1.8	4.0	1.7	3.2	5.0	8.9	3.1	2.1	2.6	4.3	3.6	42.0
1876	6.1	2.5	3.8	2.7	2.6	3.5	7.0	3.5	5.6	2.4	2.4	1.4	43.5
1877	2.9	0.7	5.3	2.7	2.3	5.6	4.0	1.8	2.2	1.9	3.5	2.4	35.3
1878	3.0	1.7	3.0	2.4	2.6	3.9	4.2	3.2	4.2	2.7	3.2	3.6	37.7
1879	3.0	2.8	4.3	1.0	2.2	4.3	4.4	6.1	2.8	0.8	3.2	4.7	39.6
1880	4.3	4.2	3.8	5.5	3.2	4.8	2.9	4.6	2.6	2.3	3.0	3.2	44.4
1881	2.9	3.4	3.8	2.4	2.2	4.4	4.1	1.6	2.5	4.7	3.6	5.0	40.6
1882	5.9	5.3	4.8	2.9	7.7	5.5	3.0	5.0	3.3	1.8	1.6	1.9	48.7
1883	2.9	7.3	2.9	4.2	5.0	4.6	3.7	1.6	2.3	5.4	3.5	4.5	47.9
1884	3.8	6.1	4.1	2.5	4.0	2.8	3.0	1.5	3.9	1.4	1.4	4.1	38.6
1885	5.3	2.3	1.0	3.6	3.7	3.6	2.3	5.8	2.6	3.6	2.6	1.8	38.2
1886	3.7	1.8	3.3	3.0	5.0	4.2	3.4	3.4	3.6	1.1	4.6	2.5	39.6
1887	2.7	7.3	2.1	5.1	3.6	3.5	3.5	2.4	2.5	0.5	2.6	2.7	38.5
1888	4.7	1.8	4.3	2.1	3.7	2.5	5.2	8.1	2.1	4.1	4.5	1.5	44.6
1889	3.8	1.6	1.3	2.0	3.5	3.9	5.7	1.3	4.0	2.1	4.7	2.5	36.4

TABLE 2.—Average precipitation in the Ohio watershed above Cincinnati, 1861 to 1910, inclusive—Continued.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
1890.....	5.3	5.9	6.4	3.3	4.9	4.5	2.3	5.1	5.6	3.9	2.6	3.5	53.3
1891.....	3.4	4.9	5.1	2.2	2.2	4.9	4.8	3.1	1.8	1.6	4.8	2.4	41.2
1892.....	2.4	4.1	3.0	4.3	5.2	4.8	4.2	3.0	3.0	0.5	2.6	2.0	38.1
1893.....	2.9	5.4	2.0	6.5	4.4	4.0	3.0	2.0	2.2	4.5	2.3	2.6	41.8
1894.....	2.5	3.7	2.2	3.0	3.6	3.0	1.9	2.8	2.9	1.5	1.9	3.4	32.4
1895.....	5.0	0.7	2.4	2.4	2.1	2.8	2.2	2.9	1.1	1.1	3.8	3.6	30.1
1896.....	1.6	2.6	4.1	1.9	3.1	4.3	9.1	3.7	4.8	1.8	3.1	1.7	41.8
1897.....	2.1	5.3	6.0	4.0	3.9	3.1	5.5	2.4	1.0	0.4	6.3	3.4	43.4
1898.....	6.7	2.1	7.2	2.3	4.5	3.9	4.2	4.2	2.7	4.0	3.1	2.7	47.6
1899.....	4.1	2.7	5.7	1.8	4.2	3.4	3.6	2.6	2.7	2.0	1.9	3.0	37.7
1900.....	2.5	3.2	2.2	1.8	2.5	2.7	3.9	3.9	1.3	1.6	5.0	1.7	32.3
1901.....	1.6	1.1	2.6	4.3	3.7	4.7	2.4	3.5	2.3	0.6	1.4	4.0	32.2
1902.....	2.4	1.1	3.1	2.2	3.2	6.8	3.1	1.7	3.4	2.4	2.7	4.8	36.9
1903.....	2.3	5.7	4.2	3.4	2.6	3.9	3.2	2.1	1.2	2.2	2.1	1.8	34.7
1904.....	2.6	2.1	5.9	2.9	3.1	3.2	2.6	2.2	1.4	1.1	0.3	3.3	30.7
1905.....	2.0	1.7	3.5	3.2	6.0	4.4	3.4	4.6	3.2	4.7	2.7	2.8	42.2
1906.....	2.5	1.6	5.3	1.6	2.3	4.1	5.2	4.5	3.3	2.1	2.9	3.9	39.3
1907.....	7.4	1.2	5.8	2.8	3.3	4.6	6.1	2.9	2.6	2.2	2.1	2.9	43.9
1908.....	1.6	4.6	6.0	4.1	4.7	2.3	3.6	2.8	0.4	1.1	1.1	2.0	34.3
1909.....	1.2	5.9	3.0	4.6	4.2	6.0	4.1	2.8	2.0	2.3	1.6	2.6	40.3
1910.....	4.8	4.3	0.3	2.9	4.3	3.2	3.7	2.1	4.6	3.7	1.4	2.7	38.0
Mean.....	3.40	3.18	3.78	3.15	3.63	3.91	4.11	3.34	2.98	2.35	2.85	3.00	39.68
1861-1870.....	3.66	2.71	4.05	3.35	3.84	3.63	3.82	3.56	4.12	2.55	2.83	3.00	41.12
1871-1880.....	3.07	2.60	3.49	3.08	2.69	3.94	5.14	3.60	2.74	2.20	2.93	3.25	38.73
1881-1890.....	4.10	4.28	3.40	3.11	4.33	3.95	3.62	3.58	3.24	2.86	3.17	3.00	42.64
1891-1900.....	3.32	3.37	3.99	3.02	3.57	3.69	4.24	3.06	2.35	1.90	3.48	2.65	38.64
1901-1910.....	2.84	2.93	3.97	3.20	3.74	4.32	3.74	2.92	2.44	2.24	1.83	3.08	37.25
1861-1885.....	3.52	3.10	3.68	3.20	3.52	3.86	4.23	3.48	3.33	2.58	2.81	3.19	40.50
1886-1910.....	3.27	3.26	3.88	3.11	3.75	3.95	4.00	3.20	2.63	2.12	2.88	2.80	38.85

TABLE No. 3.

This table shows the departure of the monthly precipitation from the normal for each month and the departure of each 10-year and each 25-year average from the normal.

TABLE 3.—Departure of monthly precipitation from normals, Ohio watershed above Cincinnati, Ohio, 1861 to 1910, inclusive.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
1861.....	-0.9	-1.2	-1.5	+1.3	+1.4	-0.4	-0.6	+1.2	+0.3	+1.2	+1.2	-1.8	+ 0.2
1862.....	+2.0	-0.1	+0.8	+2.4	-0.4	-0.6	-0.5	-1.1	-1.9	-0.7	+0.1	+0.1	+ 0.1
1863.....	+2.8	+0.3	-0.2	-1.2	-1.2	-1.2	-1.7	-0.4	-0.9	+1.3	-0.3	+0.2	- 2.5
1864.....	-1.6	-1.8	-1.2	-0.7	-0.4	-1.5	-2.6	+2.1	+1.9	±0.0	+1.6	+0.7	- 3.5
1865.....	-0.8	-0.8	+1.2	+1.3	+3.7	+0.4	+1.7	+0.5	+2.9	-0.9	-1.9	+1.8	+ 9.1
1866.....	+0.1	-0.7	-0.1	-0.5	-2.3	+0.6	+1.4	+0.6	+7.1	+0.8	-1.3	-0.8	+ 7.5
1867.....	-1.0	+1.8	+1.2	-0.5	+0.4	-0.7	-0.2	-0.5	-2.2	+0.6	-0.7	+1.2	- 0.6
1868.....	-0.3	-2.0	+1.7	+0.4	+1.9	+0.9	-1.0	+1.5	+4.6	-0.9	-0.8	-0.8	+ 5.0
1869.....	-0.5	-0.3	+0.4	-0.3	+1.0	±0.0	+0.4	-1.1	+1.0	-0.4	+0.8	+0.1	+ 1.1
1870.....	+2.8	-0.1	+0.4	-0.7	-1.7	-0.2	+0.3	-0.2	-1.6	+0.5	+1.0	-0.7	- 2.2
1871.....	-1.3	-0.5	-1.2	-1.2	-0.8	-0.6	-1.1	+1.1	-1.7	-0.6	-0.1	-0.4	- 8.4
1872.....	-2.5	-1.3	-2.3	+1.5	-0.7	-1.2	+2.1	-0.2	-1.4	+0.1	-1.8	-0.5	- 8.2
1873.....	-0.9	+0.4	-0.7	-0.3	+0.2	-0.4	+1.6	+0.5	-0.7	+2.1	-1.7	+2.0	+ 3.1
1874.....	+0.8	+0.9	-0.3	+2.0	-2.3	-1.1	+1.0	-0.9	-0.3	-1.9	+1.1	+0.5	- 0.5
1875.....	-1.7	-1.4	+0.2	-1.5	-0.4	+1.1	+4.8	-0.2	-0.9	+0.2	+1.5	+0.6	+ 2.3
1876.....	+2.7	-0.7	±0.0	-0.5	-1.0	-0.4	+2.9	+0.2	+2.6	±0.0	-0.4	-1.6	+ 3.8
1877.....	-0.5	-2.5	+1.7	-0.5	-1.3	+1.7	-0.1	-1.5	-0.8	-0.5	+0.7	-0.6	- 4.4
1878.....	-0.4	-1.5	-0.8	-0.8	-1.0	±0.0	+0.1	-0.1	+1.2	+0.3	+0.4	+0.6	- 2.0
1879.....	-0.4	-0.4	+0.5	-2.2	-1.4	+0.4	+0.3	+2.8	-0.2	-1.6	+0.4	+1.7	- 0.1
1880.....	+0.9	+1.0	±0.0	+2.3	-0.4	+0.9	-1.2	+1.3	-0.4	-0.1	+0.2	+0.2	+ 4.7
1881.....	-0.5	+0.2	±0.0	-0.8	-1.4	+0.5	±0.0	-1.7	-0.5	+2.3	+0.8	+2.0	+ 0.9
1882.....	+2.5	+2.1	+1.0	-0.3	+4.1	+1.6	-1.1	+1.7	+0.3	-0.6	-1.2	-1.1	+ 9.2
1883.....	-0.5	+4.1	-0.9	+1.0	+1.4	+0.7	-0.4	-1.7	-0.7	+3.0	+0.7	+1.5	+ 8.0



TABLE 3.—Departure of monthly precipitation from normals, Ohio watershed above Cincinnati, Ohio, 1861 to 1910, inclusive—Continued.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	An-nual.
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
1884.....	+0.4	+2.9	+0.3	-0.7	+0.4	-1.1	-1.1	-1.8	+0.9	+1.0	-1.4	+1.1	- 1.1
1885.....	+1.9	-0.9	-2.8	+0.4	+0.1	-0.3	-1.8	+2.5	-0.4	-1.2	-0.2	-1.2	- 1.5
1886.....	+0.3	-1.4	-0.5	-0.2	+1.4	+0.3	-0.7	+0.1	+0.6	-1.3	+1.8	-0.5	- 0.1
1887.....	-0.7	+4.1	-1.7	+1.9	±0.0	-0.4	-0.6	-0.9	-0.5	-1.9	-0.2	-0.3	- 1.2
1888.....	+1.3	-1.4	+0.5	-1.1	+0.1	-1.4	+1.1	+4.8	-0.9	+1.7	+1.7	-1.5	+ 4.9
1889.....	+0.4	-1.6	-2.5	-1.2	-0.1	±0.0	+1.6	-2.0	+1.0	-1.3	+1.9	-0.5	- 3.3
1890.....	+1.9	+2.7	+2.6	+0.1	+1.3	+0.6	-1.8	+1.8	+2.6	+1.5	-0.2	+0.5	+13.6
1891.....	±0.0	+1.7	+1.3	-1.0	-1.4	+1.0	+0.7	-0.2	-1.2	-0.8	+2.0	-0.6	+ 1.5
1892.....	-1.0	-0.1	-0.8	+1.1	+1.6	+0.9	+0.1	-0.3	±0.0	-1.9	-0.2	-1.0	- 1.6
1893.....	-0.5	+2.2	-1.8	+3.3	+0.8	+0.1	-1.1	-1.3	-0.3	+2.1	-0.5	-0.4	+ 2.1
1894.....	-0.9	+0.5	-1.6	-0.2	±0.0	-0.9	-2.2	-0.5	-0.1	-0.9	-0.9	+0.4	- 7.3
1895.....	+1.6	-2.5	-1.4	-0.8	-1.4	-1.1	-1.9	-0.4	-1.9	-1.3	+1.0	+0.6	- 9.6
1896.....	-1.8	-0.6	+0.3	-1.3	-0.5	+0.4	+5.0	+0.4	+1.8	-0.6	+0.3	-1.3	+ 2.1
1897.....	-1.3	+2.1	+2.2	+0.8	+0.3	-0.8	+1.4	-0.9	-2.0	-2.0	+3.5	+0.4	+ 3.7
1898.....	+3.3	-1.1	+3.4	-0.9	+0.9	±0.0	+0.1	+0.9	-0.3	+1.6	+0.3	-0.3	+ 7.9
1899.....	+0.7	-0.5	+1.9	-1.4	+0.6	-0.5	-0.5	-0.7	-0.3	-0.4	+0.9	±0.0	- 2.0
1900.....	-0.9	±0.0	-1.6	-1.4	-1.1	-1.2	-0.3	+0.6	-1.7	-0.8	+2.2	-1.3	- 7.4
1901.....	-1.8	-2.1	-1.1	+1.1	+0.1	+0.8	-1.7	+0.2	-0.7	-1.8	-1.4	+1.0	- 7.5
1902.....	-1.0	-2.1	-0.7	-1.0	-0.4	+2.9	-1.0	-1.6	+0.4	±0.0	-0.1	+1.3	- 2.8
1903.....	-1.1	+2.5	+0.4	+0.2	-1.0	±0.0	-0.9	-1.2	-1.3	-0.2	-0.7	-1.2	- 5.0
1904.....	-0.8	-1.1	+2.1	-0.3	-0.5	-0.7	-1.5	-1.1	-1.6	-1.3	-2.5	+0.3	- 9.0
1905.....	-1.4	-1.5	-0.3	±0.0	+2.4	+0.5	-0.7	+1.3	+0.2	+2.3	-0.1	-0.2	+ 2.5
1906.....	-0.9	-1.6	+1.5	-1.6	-1.3	+0.2	+1.1	+1.2	+0.3	-0.3	+0.1	+0.9	- 0.4
1907.....	+4.0	-2.0	+2.0	-0.4	-0.3	+0.7	+2.0	-0.4	-0.4	-0.2	-0.7	-0.1	+ 4.2
1908.....	-1.8	+1.4	+2.2	+0.9	+1.1	-1.6	-0.5	-0.5	-2.6	-1.3	-1.7	-1.0	- 5.4
1909.....	-2.2	+2.7	-0.8	+1.4	+0.6	+2.1	±0.0	-0.5	-1.0	-0.1	-1.2	-0.4	+ 0.6
1910.....	+1.4	+1.1	-3.5	-0.3	+0.7	-0.7	-0.4	-1.2	+1.6	+1.3	-1.4	-0.3	- 1.7
1861-1870.....	+0.3	-0.5	+0.2	+0.2	+0.2	-0.3	-0.3	+0.3	+1.1	+0.2	±0.0	±0.0	+ 1.5
1871-1880.....	-0.3	-0.6	-0.3	-0.1	-0.9	±0.0	+1.0	+0.3	-0.3	-0.2	+0.1	+0.2	- 1.3
1881-1890.....	+0.7	+1.1	-0.4	-0.1	+0.7	+0.1	-0.5	+0.3	+0.2	+0.5	+0.4	±0.0	+ 3.0
1891-1900.....	-0.1	+0.2	+0.2	-0.2	±0.0	-0.2	+0.1	-0.2	-0.6	-0.5	+0.7	-0.4	- 1.0
1901-1910.....	-0.6	-0.3	+0.2	±0.0	+0.1	+0.4	-0.4	-0.4	-0.6	-0.2	-1.0	+0.1	- 2.7
1861-1885.....	+0.1	-0.1	-0.1	±0.0	-0.1	±0.0	+0.1	+0.2	+0.4	+0.2	±0.0	+0.2	+ 0.8
1886-1910.....	-0.1	+0.1	+0.1	-0.1	+0.2	+0.1	-0.1	-0.1	-0.4	-0.3	+0.1	-0.2	- 0.8

TABLE NO. 4.

The number of days that the river stages were between each 5 or 10 feet for each month and the year for each 10-year period is shown in Table 5, together with the totals for the 50 years and the means for each 10-year period. The yearly averages can be obtained by dividing the 10-year averages by 10.

If it is true that the cutting away of the forests has increased flood conditions and intensified low-water periods, it seems to the writer that there would be a regular increase in the low-water days in the months of July, August, and September, and that this increase would appear in the 10-year periods in the table. On the contrary, there were only 64 days from 1901 to 1910, inclusive, when the river was between 5 and 10 feet during the month of July, as compared with 179 days from 1861 to 1870, inclusive. In October there were only 96 days in the 10 years from 1901 to 1910, inclusive, when the river was below 5 feet, as compared with 177 days in the 10 years from 1871 to 1880, inclusive. The high-water days should show a regular increase also during the months from January to April, inclusive, but such is not the case.

**TABLE 4.**—*Total number of days in each month with river readings between values indicated at Cincinnati, 10-year periods, 1861 to 1910, inclusive.*

**0 TO 4.9 FEET.**

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1861-1870.....	0	0	0	0	0	8	18	41	88	93	30	8	286
1871-1880.....	0	0	0	0	0	0	18	29	100	177	66	1	391
1881-1890.....	0	0	0	0	0	0	11	42	124	113	65	8	363
1891-1900.....	0	0	0	0	0	5	19	53	96	193	68	1	435
1901-1910.....	0	0	0	0	0	0	0	17	73	96	84	36	306

**5 TO 9.9 FEET.**

1861-1870.....	6	10	0	0	9	81	179	171	97	114	121	48	836
1871-1880.....	34	14	6	4	46	160	145	167	159	107	79	63	984
1881-1890.....	9	7	4	1	10	50	132	147	68	108	48	41	625
1891-1900.....	29	0	0	0	38	72	154	150	181	62	134	79	899
1901-1910.....	14	22	7	0	23	26	64	164	141	142	124	80	807

**10 TO 19.9 FEET.**

1861-1870.....	124	86	34	29	147	167	94	98	82	72	95	140	1,168
1871-1880.....	102	93	72	116	162	135	127	100	22	22	133	147	1,231
1881-1890.....	89	49	79	95	172	161	135	112	89	58	100	171	1,310
1891-1900.....	128	81	48	89	149	185	115	84	23	46	80	161	1,189
1901-1910.....	137	104	34	71	147	175	204	123	86	71	71	103	1,326

**20 TO 29.9 FEET.**

1861-1870.....	90	99	116	152	99	44	19	0	21	22	53	71	786
1871-1880.....	96	106	122	104	74	5	6	3	12	4	17	54	603
1881-1890.....	119	67	105	101	78	66	30	6	14	23	63	65	737
1891-1900.....	74	82	111	128	90	34	16	11	0	9	15	64	634
1901-1910.....	86	80	86	133	92	76	42	6	0	1	17	54	673

**30 TO 39.9 FEET.**

1861-1870.....	64	59	99	70	45	0	0	0	8	7	1	36	389
1871-1880.....	50	43	94	61	21	0	14	2	7	0	5	32	329
1881-1890.....	56	45	69	60	39	23	2	3	5	8	24	17	360
1891-1900.....	42	67	104	55	22	4	4	10	0	0	3	6	317
1901-1910.....	40	45	69	58	26	18	0	0	0	0	4	29	289

**40 TO 49.9 FEET.**

1861-1870.....	14	21	44	43	8	0	0	0	4	2	0	7	143
1871-1880.....	23	23	16	15	7	0	0	4	0	0	0	18	101
1881-1890.....	37	55	38	22	11	0	0	0	0	0	0	8	171
1891-1900.....	32	30	31	23	9	0	2	2	0	0	0	1	130
1901-1910.....	22	25	80	25	21	5	0	0	0	0	0	8	186

**50 TO 59.9 FEET.**

1861-1870.....	12	7	17	6	2	0	0	0	0	0	0	0	44
1871-1880.....	6	4	0	0	0	0	0	5	0	0	0	0	15
1881-1890.....	0	39	15	12	0	0	0	0	0	0	0	0	66
1891-1900.....	5	20	14	5	2	0	0	0	0	0	0	0	46
1901-1910.....	5	6	30	13	1	0	0	0	0	0	0	0	55

**60 TO 69.9 FEET.**

[illegible]

**TABLE 4.**—*Total number of days in each month with river readings between values indicated at Cincinnati, 10-year periods, 1861 to 1910, inclusive—Continued.*

**70 TO 79.9 FEET.**

<b>Years.</b>	<b>Jan.</b>	<b>Feb.</b>	<b>Mar.</b>	<b>Apr.</b>	<b>May.</b>	<b>June.</b>	<b>July.</b>	<b>Aug.</b>	<b>Sept.</b>	<b>Oct.</b>	<b>Nov.</b>	<b>Dec.</b>	<b>Total.</b>
	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1861-1870.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1871-1880.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1881-1890.....	0	.2	0	0	0	0	0	0	0	0	0	0	2
1891-1900.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1901-1910.....	0	0	0	0	0	0	0	.0	0	0	0	0	0

*Totals for 50 years and means for each 10-year period.*

**0 TO 4.9 FEET.**

<b>Sums.....</b>	0	0	0	0	0	13	66	182	481	672	313	54	1,781
<b>Means.....</b>	0	0	0	0	0	3	13	36	96	134	63	11	356

**5 TO 9.9 FEET.**

<b>Sums.....</b>	<b>92</b>	<b>53</b>	<b>17</b>	<b>5</b>	<b>126</b>	<b>389</b>	<b>674</b>	<b>799</b>	<b>646</b>	<b>533</b>	<b>508</b>	<b>309</b>	<b>4,149</b>
<b>Means.....</b>	<b>18</b>	<b>11</b>	<b>3</b>	<b>1</b>	<b>25</b>	<b>78</b>	<b>135</b>	<b>160</b>	<b>129</b>	<b>107</b>	<b>101</b>	<b>62</b>	<b>830</b>

**10 TO 19.9 FEET.**

<b>Sums.....</b>	<b>580</b>	<b>413</b>	<b>287</b>	<b>400</b>	<b>777</b>	<b>824</b>	<b>675</b>	<b>517</b>	<b>302</b>	<b>289</b>	<b>479</b>	<b>722</b>	<b>6,225</b>
<b>Means.....</b>	<b>116</b>	<b>83</b>	<b>53</b>	<b>80</b>	<b>155</b>	<b>165</b>	<b>135</b>	<b>103</b>	<b>60</b>	<b>54</b>	<b>96</b>	<b>144</b>	<b>1,244</b>

**20 TO 29.9 FEET.**

<b>Sums.....</b>	<b>464</b>	<b>434</b>	<b>540</b>	<b>619</b>	<b>433</b>	<b>235</b>	<b>113</b>	<b>26</b>	<b>47</b>	<b>59</b>	<b>165</b>	<b>308</b>	<b>3,433</b>
<b>Means.....</b>	<b>93</b>	<b>87</b>	<b>108</b>	<b>124</b>	<b>87</b>	<b>47</b>	<b>23</b>	<b>5</b>	<b>9</b>	<b>12</b>	<b>83</b>	<b>62</b>	<b>687</b>

**30 TO 39.9 FEET.**

<b>Sums.....</b>	252	259	435	313	153	45	20	15	20	15	37	120	1,685
<b>Means.....</b>	50	52	85	63	31	9	4	3	4	3	7	24	337

**40 TO 49.9 FEET.**

<b>Sums</b> .....	128	154	209	128	56	5	2	6	4	2	0	37	731
<b>Means</b> .....	26	31	42	26	11	1	0	1	1	0	0	7	146

**50 TO 59.9 FEET.**

<b>Sums.....</b>	<b>28</b>	<b>76</b>	<b>76</b>	<b>36</b>	<b>5</b>	<b>0</b>	<b>0</b>	<b>5</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>226</b>
<b>Means.....</b>	<b>6</b>	<b>15</b>	<b>15</b>	<b>7</b>	<b>1</b>	<b>0</b>	<b>0</b>	<b>1</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>45</b>

**60 TO 69.9 FEET.**

[illegible]

**70 TO 79.9 FEET.**

[illegible]

TABLE 4.—Total number of days in each month with river readings between values indicated at Cincinnati, 10-year periods, 1861 to 1910, inclusive.

**0 TO 4.9 FEET.**

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1861-1870.....	0	0	0	0	0	8	18	41	88	93	30	8	286
1871-1880.....	0	0	0	0	0	0	18	29	100	177	66	1	391
1881-1890.....	0	0	0	0	0	0	11	42	124	113	65	8	363
1891-1900.....	0	0	0	0	0	5	19	53	96	193	68	1	435
1901-1910.....	0	0	0	0	0	0	0	17	73	96	84	36	306

**5 TO 9.9 FEET.**

1861-1870.....	6	10	0	0	9	81	179	171	97	114	121	48	838
1871-1880.....	34	14	6	4	46	160	145	167	159	107	79	63	984
1881-1890.....	9	7	4	1	10	50	132	147	68	106	48	41	625
1891-1900.....	29	0	0	0	38	72	154	150	181	62	134	79	899
1901-1910.....	14	22	7	0	23	26	64	164	141	142	124	80	807

**10 TO 19.9 FEET.**

1861-1870.....	124	86	34	29	147	167	94	98	82	72	95	140	1,168
1871-1880.....	102	93	72	116	162	135	127	100	22	22	133	147	1,231
1881-1890.....	89	49	79	95	172	161	135	112	89	58	100	171	1,310
1891-1900.....	128	81	48	89	149	185	115	84	23	46	80	161	1,189
1901-1910.....	137	104	34	71	147	175	204	123	86	71	71	103	1,326

**20 TO 20.9 FEET.**

1861-1870.....	90	99	116	152	99	44	19	0	21	22	53	71	786
1871-1880.....	96	106	122	104	74	5	6	3	12	4	17	54	603
1881-1890.....	119	67	105	101	78	66	30	6	14	23	63	65	737
1891-1900.....	74	82	111	128	90	34	16	11	0	9	15	64	634
1901-1910.....	86	80	88	133	92	76	42	6	0	1	17	54	673

### 30 TO 39.9 FEET.

1861-1870.....	64	59	99	70	45	0	0	0	8	7	1	36	389
1871-1880.....	50	43	94	61	21	0	14	2	7	0	5	32	329
1881-1890.....	56	45	69	69	39	23	2	3	5	8	24	17	360
1891-1900.....	42	67	104	55	22	4	4	10	0	0	3	6	317
1901-1910.....	40	45	69	58	26	18	0	0	0	0	4	29	289

**40 TO 49.9 FEET.**

1861-1870.....	14	21	44	43	8	0	0	0	4	2	0	7	143
1871-1880.....	23	23	16	15	7	0	0	4	0	0	0	13	101
1881-1890.....	37	55	38	22	11	0	0	0	0	0	0	8	171
1891-1900.....	32	30	31	23	9	0	2	2	0	0	0	1	130
1901-1910.....	22	25	80	25	21	5	0	0	0	0	0	8	186

### 50 TO 59.9 FEET.

1861-1870.....	12	7	17	6	2	0	0	0	0	0	0	0	44
1871-1880.....	6	4	0	0	0	0	0	5	0	0	0	0	15
1881-1890.....	0	39	15	12	0	0	0	0	0	0	0	0	66
1891-1900.....	5	20	14	5	2	0	0	0	0	0	0	0	46
1901-1910.....	5	6	30	13	1	0	0	0	0	0	0	0	55

**60 TO 69.9 FEET.**

[illegible]

**TABLE 4.**—*Total number of days in each month with river readings between values indicated at Cincinnati, 10-year periods, 1861 to 1910, inclusive—Continued.*

**70 TO 79.9 FEET.**

<b>Years.</b>	<b>Jan.</b>	<b>Feb.</b>	<b>Mar.</b>	<b>Apr.</b>	<b>May.</b>	<b>June.</b>	<b>July.</b>	<b>Aug.</b>	<b>Sept.</b>	<b>Oct.</b>	<b>Nov.</b>	<b>Dec.</b>	<b>Total.</b>
	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1861-1870.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1871-1880.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1881-1890.....	0	.2	0	0	0	0	0	0	0	0	0	0	2
1891-1900.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1901-1910.....	0	0	0	0	0	0	0	.0	0	0	0	0	0

*Totals for 50 years and means for each 10-year period.*

### 0 TO 49 FEET.

<b>Sums.....</b>	0	0	0	0	0	13	66	182	481	672	313	54	1,781
<b>Means.....</b>	0	0	0	0	0	3	13	36	96	134	63	11	356

**5 TO 9.9 FEET.**

<b>Sums.....</b>	<b>92</b>	<b>53</b>	<b>17</b>	<b>5</b>	<b>128</b>	<b>389</b>	<b>674</b>	<b>799</b>	<b>646</b>	<b>533</b>	<b>506</b>	<b>309</b>	<b>4,149</b>
<b>Means.....</b>	<b>18</b>	<b>11</b>	<b>3</b>	<b>1</b>	<b>25</b>	<b>78</b>	<b>135</b>	<b>160</b>	<b>129</b>	<b>107</b>	<b>101</b>	<b>62</b>	<b>830</b>

**10 TO 19.9 FEET.**

<b>Sums.....</b>	<b>580</b>	<b>413</b>	<b>267</b>	<b>400</b>	<b>777</b>	<b>824</b>	<b>675</b>	<b>517</b>	<b>302</b>	<b>269</b>	<b>479</b>	<b>722</b>	<b>6,225</b>
<b>Means.....</b>	<b>116</b>	<b>83</b>	<b>53</b>	<b>80</b>	<b>155</b>	<b>165</b>	<b>135</b>	<b>103</b>	<b>60</b>	<b>54</b>	<b>96</b>	<b>144</b>	<b>1,244</b>

**20 TO 29.9 FEET.**

<b>Sums.....</b>	<b>464</b>	<b>434</b>	<b>540</b>	<b>619</b>	<b>433</b>	<b>235</b>	<b>113</b>	<b>28</b>	<b>47</b>	<b>59</b>	<b>105</b>	<b>308</b>	<b>3,433</b>
<b>Means.....</b>	<b>93</b>	<b>87</b>	<b>108</b>	<b>124</b>	<b>87</b>	<b>47</b>	<b>23</b>	<b>5</b>	<b>9</b>	<b>12</b>	<b>33</b>	<b>62</b>	<b>687</b>

**30 TO 39.9 FEET.**

<b>Sums.....</b>	<b>252</b>	<b>259</b>	<b>435</b>	<b>313</b>	<b>153</b>	<b>45</b>	<b>20</b>	<b>15</b>	<b>20</b>	<b>15</b>	<b>37</b>	<b>120</b>	<b>1,685</b>
<b>Means.....</b>	<b>50</b>	<b>52</b>	<b>85</b>	<b>63</b>	<b>31</b>	<b>9</b>	<b>4</b>	<b>3</b>	<b>4</b>	<b>3</b>	<b>7</b>	<b>24</b>	<b>337</b>

**40 TO 49.9 FEET.**

<b>Sums.....</b>	128	154	209	128	56	5	2	6	4	2	0	37	731
<b>Means.....</b>	26	31	42	26	11	1	0	1	1	0	0	7	146

**50 TO 59.9 FEET.**

<b>Sums.....</b>	<b>28</b>	<b>76</b>	<b>76</b>	<b>36</b>	<b>5</b>	<b>0</b>	<b>0</b>	<b>5</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>226</b>
<b>Means.....</b>	<b>6</b>	<b>15</b>	<b>15</b>	<b>7</b>	<b>1</b>	<b>0</b>	<b>0</b>	<b>1</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>45</b>

**60 TO 69.9 FEET.**

[illegible]

**70 TO 79.9 FEET.**

[illegible]

TABLE No. 5.

This table shows the number of days the river at Cincinnati was between each 5 or 10 feet for each month and the year for the two 25-year periods, 1861 to 1885 and 1886 to 1910, all inclusive.

It will be seen that there was very little difference between the total number of flood days of the two periods during the months of January and February, while during the months of March and April the greater number occurred in the second period. It will also be seen that the low-water days were in excess in the first period during the months from June to September, inclusive, while during the second period the low-water days were in excess in November and December.

Flood conditions are not the products of precipitation extending over any considerable period of time, but are, as a rule, the results of abnormal precipitation within a comparatively short time, and there is therefore no direct relation between the average annual precipitation and the number of flood days and the intensity of flood conditions. On the other hand, low-water periods are usually the results of prolonged periods of deficient precipitation, and the relation between the two is therefore quite clearly marked.

TABLE 5.—Total number of days in each month with river readings between values indicated at Cincinnati, 25-year periods, 1861 to 1910, inclusive.

## 0.0 TO 4.9 FEET.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.
1861-1885.....	0	0	0	0	0	8	39	93	271	335	120	13	879
1886-1910.....	0	0	0	0	0	5	27	89	210	337	193	41	902

## 5 TO 9.9 FEET.

1861-1885.....	45	28	10	5	57	261	397	408	275	280	242	126	2,133
1886-1910.....	47	25	7	0	69	128	277	391	371	253	264	184	2,016

## 10 TO 19.9 FEET.

1861-1885.....	275	203	128	181	403	385	289	259	152	125	301	389	3,090
1886-1910.....	305	210	139	219	374	439	386	258	150	144	178	333	3,135

## 20 TO 29.9 FEET.

1861-1885.....	234	228	300	317	215	81	36	4	33	26	81	137	1,692
1886-1910.....	230	206	240	302	218	144	77	22	14	33	84	171	1,741

## 30 TO 39.9 FEET.

1861-1885.....	138	120	239	171	79	16	14	2	15	7	6	83	890
1886-1910.....	114	139	196	141	74	29	6	13	5	8	31	37	793

## 40 TO 49.9 FEET.

1861-1885.....	65	70	81	70	19	0	0	4	4	2	0	28	343
1886-1910.....	63	84	128	58	37	5	2	2	0	0	0	9	388

TABLE 5.—Total number of days in each month with river readings between values indicated at Cincinnati, 25-year periods, 1861 to 1910, inclusive—Continued.

## 50 TO 59.9 FEET.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.
1861-1885.....	13	37	17	6	2	0	0	5	0	0	0	0	85
1886-1910.....	10	39	59	30	3	0	0	0	0	0	0	0	141

## 60 TO 69.9 FEET.

1861-1885.....	0	18	0	0	0	0	0	0	0	0	0	0	18
1886-1910.....	6	2	6	0	0	0	0	0	0	0	0	0	14

## 70 TO 79.9 FEET.

1861-1885.....	0	2	0	0	0	0	0	0	0	0	0	0	2
1886-1910.....	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE No. 6.

In this table is given the average precipitation and the average number of days the river at Cincinnati was above 50 feet, below 5 feet, and below 10 feet for each month and the year for each 10-year and each 25-year period.

TABLE 6.—Average precipitation in the Ohio watershed above Cincinnati, and days with the river above 50 feet, below 5 feet, and below 10 feet at Cincinnati, 1861-1910, inclusive.

## 1861 TO 1870, INCLUSIVE.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.
Rainfall (inches).....	3.7	2.7	4.0	3.4	3.8	3.6	3.5	3.6	4.1	2
Days with river above 50 feet.....	12	7	17	6	2	0	0	0	0	
Days with river below 5 feet.....	0	0	0	0	0	8	18	41	88	
Days with river below 10 feet.....	6	10	0	0	9	89	197	212	185	2

## 1871 TO 1880, INCLUSIVE.

Rainfall (inches).....	3.1	2.6	3.5	3.1	2.7	3.9	5.1	3.6	2.7	2.2	2.9	2.3	38.6
Days with river above 50 feet.....	6	4	0	0	0	0	0	5	0	0	0	0	15
Days with river below 5 feet.....	0	0	0	0	0	0	18	29	100	177	66	1	391
Days with river below 10 feet.....	34	14	0	4	46	160	163	196	259	284	145	64	1,376

## 1881 TO 1890, INCLUSIVE.

Rainfall (inches).....	4.1	4.3	3.4	3.1	4.3	4.0	3.6	3.6	3.2	2.9	3.2	3.0	42.7
Days with river above 50 feet.....	0	59	15	12	0	0	0	0	0	0	0	0	86
Days with river below 5 feet.....	0	0	0	0	0	0	11	42	124	113	65	8	393
Days with river below 10 feet.....	9	7	4	1	10	50	143	189	192	221	113	49	983

## 1891 TO 1900, INCLUSIVE.

Rainfall (inches).....	3.3	3.4	4.0	3.0	3.6	3.7	4.2	3.1	2.4	1.9	3.5	2.6	38.7
Days with river above 50 feet.....	5	22	16	5	2	0	0	0	0	0	0	0	50
Days with river below 5 feet.....	0	0	0	0	0	5	19	53	96	193	63	1	435
Days with river below 10 feet.....	29	0	0	0	38	77	173	203	277	255	202	78	1,332



TABLE 6.—Average precipitation in the Ohio watershed above Cincinnati, and days with the river above 50 feet, below 5 feet, and below 10 feet at Cincinnati, 1861–1910, inclusive—Continued.

1901 TO 1910, INCLUSIVE.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Rainfall (inches).....	2.8	2.9	4.0	3.2	3.7	4.3	3.7	2.9	2.4	2.2	1.8	3.1	37.0
Days with river above 50 feet.....	11	6	34	13	1	0	0	0	0	0	0	0	65
Days with river below 5 feet.....	0	0	0	0	0	0	0	17	73	96	84	36	306
Days with river below 10 feet.....	14	22	7	0	23	26	64	181	214	238	208	116	1,113

1861 TO 1885, INCLUSIVE.

	3.5	3.1	3.7	3.2	3.5	3.9	4.2	3.5	3.3	2.6	2.8	3.2	40.5
Rainfall (inches).....	3.5	3.1	3.7	3.2	3.5	3.9	4.2	3.5	3.3	2.6	2.8	3.2	40.5
Days with river above 50 feet.....	18	57	17	6	2	0	0	5	0	0	0	0	106
Days with river below 5 feet.....	0	0	0	0	0	8	39	93	271	335	120	13	879
Days with river below 10 feet.....	45	28	10	5	57	269	436	501	546	615	362	138	3,012

1886 TO 1910, INCLUSIVE.

	3.3	3.3	3.9	3.1	3.8	4.0	4.0	3.2	2.6	2.1	2.9	2.8	38.8
Rainfall (inches).....	3.3	3.3	3.9	3.1	3.8	4.0	4.0	3.2	2.6	2.1	2.9	2.8	38.8
Days with river above 50 feet.....	16	41	65	30	3	0	0	0	0	0	0	0	155
Days with river below 5 feet.....	0	0	0	0	0	5	27	89	210	337	193	41	902
Days with river below 10 feet.....	47	25	7	0	69	133	306	480	581	590	457	215	2,910

TABLE No. 7.

This table is supplementary to Table 6, and gives the departures from the normals for the same data as are shown in Table 6. In these tables we begin to observe the effect of precipitation upon river stages.

TABLE 7.—Departures of precipitation and river-stage days from normals at Cincinnati for days above 50 feet, below 5 feet, and below 10 feet, 1861–1910.

1861 TO 1870, INCLUSIVE.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Precipitation (inches).....	+0.3	-0.5	+0.2	+0.2	+0.2	-0.3	-0.3	+0.3	+1.1	+0.2	0	0	+1.5
Days above 50 feet.....	+ 5	- 13	+ 1	- 2	+ 1	.....	.....	- 1	.....	.....	.....	.....	- 8
Days below 5 feet.....	.....	.....	.....	.....	.....	+ 5	+ 5	+ 5	- 8	- 39	- 33	- 3	- 70
Days below 10 feet.....	- 12	- 1	- 3	- 1	- 17	+ 9	+ 48	+ 16	- 45	- 34	- 13	- 17	- 65

1871 TO 1880, INCLUSIVE.

Precipitation (inches).....	-0.3	-0.6	-0.3	-0.1	-0.9	0	+1.0	+0.3	-0.3	-0.2	+0.1	+0.2	-1.3
Days above 50 feet.....	- 1	- 16	- 16	- 8	- 1	.....	.....	0	.....	.....	.....	.....	- 37
Days below 5 feet.....	.....	.....	.....	.....	.....	- 3	+ 5	- 7	+ 4	+ 43	+ 3	- 10	+ 35
Days below 10 feet.....	+ 16	+ 3	+ 3	+ 3	+ 21	+ 80	+ 14	0	+ 34	+ 43	- 19	- 9	+ 188

1881 TO 1890, INCLUSIVE.

Precipitation (inches).....	+0.7	+1.1	-0.4	-0.1	+0.7	+0.1	-0.5	+0.3	+0.2	+0.5	+0.4	0	+3.0
Days above 50 feet.....	- 7	+ 39	- 1	+ 4	- 1	.....	.....	- 1	.....	.....	.....	.....	+ 34
Days below 5 feet.....	.....	.....	.....	.....	.....	- 3	- 4	+ 6	+ 28	- 21	+ 2	- 3	+ 7
Days below 10 feet.....	- 9	- 4	+ 1	0	- 15	- 30	- 5	- 7	- 33	- 20	- 54	+ 24	- 198

**TABLE 7.—Departures of precipitation and river-stage days from normals at Cincinnati for days above 50 feet, below 5 feet, and below 10 feet, 1861–1910, inclusive—Continued.**

1891 TO 1900, INCLUSIVE.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Precipitation (inches).....	-0.1	+0.2	+0.2	-0.2	0	-0.2	+0.1	-0.2	-0.6	-0.5	+0.7	-0.4	-1.0
Days above 50 feet.....	- 2	+ 2	0	- 3	+ 1	.....	.....	- 1	.....	.....	.....	.....	- 2
Days below 5 feet.....	.....	.....	.....	.....	.....	+ 2	+ 6	+ 17	0	+ 59	+ 5	- 10	+ 79
Days below 10 feet.....	+ 11	- 11	- 3	- 1	+ 13	- 3	+ 24	+ 7	+ 52	+ 14	+ 38	+ 5	+ 145

1901 TO 1910, INCLUSIVE.

Precipitation (inches).....	-0.6	-0.3	+0.2	0	+0.1	+0.4	-0.4	-0.4	-0.6	-0.2	-1.0	+0.1	-2.7
Days above 50 feet.....	+ 4	- 14	+ 18	+ 5	0	.....	.....	- 1	.....	.....	.....	.....	+ 13
Days below 5 feet.....	.....	.....	.....	.....	.....	- 3	- 13	- 19	- 23	- 38	+ 21	+ 25	- 50
Days below 10 feet.....	- 4	+ 11	+ 4	- 1	- 2	- 54	- 85	- 15	- 11	- 3	+ 44	+ 43	- 74

1861 TO 1885, INCLUSIVE.

Precipitation (inches).....	+0.1	-0.1	-0.1	0	-0.1	0	+0.1	+0.2	+0.3	+0.2	0	+0.2	+0.8
Days above 50 feet.....	+ 1	+ 8	- 24	- 12	0	.....	.....	+ 3	.....	.....	.....	.....	- 25
Days below 5 feet.....	.....	.....	.....	.....	.....	+ 2	+ 6	+ 2	+ 31	- 1	- 36	- 14	- 11
Days below 10 feet.....	- 1	+ 2	+ 2	+ 3	- 6	+ 68	+ 67	+ 11	- 18	+ 13	- 48	- 44	+ 49

1886 TO 1910, INCLUSIVE.

Precipitation (inches).....	-0.1	+0.1	+0.1	-0.1	+0.2	+0.1	-0.1	-0.1	-0.4	-0.3	+0.1	-0.2	-0.8
Days above 50 feet.....	- 1	- 8	+ 24	+ 12	+ 1	.....	.....	- 2	.....	.....	.....	.....	+ 25
Days below 5 feet.....	.....	.....	.....	.....	.....	- 1	- 6	- 2	- 30	+ 1	+ 37	+ 14	+ 11
Days below 10 feet.....	+ 1	- 1	- 1	- 2	+ 6	- 68	- 68	- 10	+ 17	- 12	+ 47	+ 43	- 48

**TABLE No. 8.**

In this table is shown the comparison between the departures of the precipitation from the normals for each month of each 10 years, and the number of days the river stages were above or below the normal number of days for the different 5 or 10 foot heights for the same 10-year periods.

**TABLE 8.—Departures of precipitation and river-stage days from normals, Ohio Watershed above Cincinnati, 1861 to 1910, inclusive.**

PRECIPITATION.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1861–1870.....	+0.3	-0.5	+0.2	+0.2	+0.2	-0.3	-0.3	+0.3	+1.1	+0.2	0	0	+1.5
1871–1880.....	-0.3	-0.6	-0.3	-0.1	-0.9	0	+1.0	+0.3	-0.3	-0.2	+0.1	+0.2	-1.3
1881–1890.....	+0.7	+1.1	-0.4	-0.1	+0.7	+0.1	-0.5	+0.3	+0.2	+0.5	+0.4	0	+3.0
1891–1900.....	-0.1	+0.2	+0.2	-0.2	0	-0.2	+0.1	-0.2	-0.6	-0.5	+0.7	-0.4	-1.0
1901–1910.....	-0.6	-0.3	+0.2	0	+0.1	+0.4	-0.4	-0.4	-0.6	-0.2	-1.0	+0.1	-2.7

DAYS WITH RIVER 0 TO 4.9 FEET, INCLUSIVE.

1861–1870.....	.....	.....	.....	.....	.....	+ 5	+ 5	+ 5	- 8	-39	-33	- 3	-70
1871–1880.....	.....	.....	.....	.....	.....	- 3	+ 5	- 7	+ 4	+43	+ 3	-10	+35
1881–1890.....	.....	.....	.....	.....	.....	- 3	- 4	+ 6	+28	-21	+ 2	- 3	+ 7
1891–1900.....	.....	.....	.....	.....	.....	+ 2	+ 6	+17	0	+59	+ 5	-10	+79
1901–1910.....	.....	.....	.....	.....	.....	- 3	-13	-19	-23	-38	+21	+25	-50

TABLE 8.—Departures of precipitation and river-stage days from normals, Ohio watershed above Cincinnati, 1861 to 1910, inclusive—Continued.

**DAYS WITH RIVER 5 TO 9.9 FEET, INCLUSIVE.**

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	An- nual.
1861-1870.....	-12	- 1	- 3	- 1	-16	+ 3	+44	+11	-32	+ 7	+20	-14	+ 6
1871-1880.....	+16	+ 3	+ 3	+ 3	+21	+82	+10	+ 6	+80	0	-22	+ 1	+154
1881-1890.....	- 9	- 4	+ 1	0	-15	-28	- 1	-13	-61	+ 1	-53	-21	-203
1891-1900.....	+11	-11	- 3	- 1	+13	- 6	+19	-10	+52	-45	+33	+15	+ 69
1901-1910.....	- 4	+11	+ 4	- 1	- 2	-52	-71	+ 4	+12	+25	+13	+18	- 23

**DAYS WITH RIVER 10 TO 19.9 FEET, INCLUSIVE.**

1861-1870.....	+ 8	+ 2	-19	-51	- 8	+ 2	-41	- 5	+22	+18	- 1	- 4	-76
1871-1880.....	-14	+10	+19	+36	+ 7	-30	- 8	- 3	-38	-32	+37	+ 3	-13
1881-1890.....	-27	-34	+26	+15	+17	- 4	- 2	+ 9	+29	+ 4	+ 4	+27	+64
1891-1900.....	+12	- 2	- 7	+ 9	- 6	+20	-20	-19	-37	- 8	-16	+17	-55
1901-1910.....	+21	+21	-19	- 9	- 8	+10	+69	+20	+26	+17	-25	-41	+82

**DAYS WITH RIVER 20 TO 29.9 FEET, INCLUSIVE.**

1861-1870.....	- 3	+12	+ 8	+28	+12	- 3	- 4	- 5	+12	+10	+20	+ 9	+99
1871-1880.....	+ 3	+19	+14	-20	-13	-42	-17	- 2	+ 3	- 8	-16	- 8	-84
1881-1890.....	+26	-20	- 3	-23	- 9	+19	+ 7	+ 1	+ 5	+11	+30	+ 3	+50
1891-1900.....	-19	- 5	+ 3	+ 4	+ 3	-13	- 7	+ 6	- 9	- 3	-18	+ 2	-53
1901-1910.....	- 7	- 7	-22	+ 9	+ 5	+29	+19	+ 1	- 9	-11	-16	- 8	-14

**DAYS WITH RIVER 30 TO 39.9 FEET, INCLUSIVE.**

1861-1870.....	+14	+ 7	+12	+ 7	+14	- 9	- 4	- 3	+ 4	+ 4	- 6	+12	+52
1871-1880.....	0	- 9	+ 7	- 2	-10	- 9	+10	- 1	+ 3	- 3	- 2	+ 8	- 8
1881-1890.....	+ 6	- 7	-18	+ 6	+ 8	+14	- 2	0	+ 1	+ 5	+17	- 7	+23
1891-1900.....	- 8	+15	+17	- 8	- 9	- 5	0	+ 7	- 4	- 3	- 4	-18	-20
1901-1910.....	-10	- 7	-18	- 5	- 5	+ 9	- 4	- 3	- 4	- 3	- 3	+ 5	-48

**DAYS WITH RIVER 40 TO 49.9 FEET, INCLUSIVE.**

1861-1870.....	-12	-10	+ 2	+17	- 3	- 1	0	- 1	+ 3	+ 2	0	- 3
1871-1880.....	- 3	- 8	-26	-11	- 4	- 1	0	+ 3	- 1	0	+ 6	-45
1881-1890.....	+ 9	+24	- 4	- 4	0	- 1	0	- 1	- 1	0	+ 1	+25
1891-1900.....	+ 6	- 1	-11	- 3	- 2	- 1	+ 2	+ 1	- 1	0	- 6	-16
1901-1910.....	- 4	- 6	+38	- 1	+10	+ 4	0	- 1	- 1	0	+ 1	+40

**DAYS WITH RIVER 50 TO 59.9 FEET, INCLUSIVE.**

[illegible]

**DAYS WITH RIVER 60 TO 69.9 FEET, INCLUSIVE.**

1861-1870.....	- 1	- 4	- 1	.....	.....	.....	.....	- 6
1871-1880.....	- 1	- 4	- 1	.....	.....	.....	.....	- 6
1881-1890.....	- 1	+ 14	- 1	.....	.....	.....	.....	+ 12
1891-1900.....	- 1	- 2	+ 1	.....	.....	.....	.....	- 2
1901-1910.....	+ 5	- 4	+ 3	.....	.....	.....	.....	+ 4

**DAYS WITH RIVER 70 TO 79.9 FEET, INCLUSIVE.**

[illegible]

TABLE NO. 9.

This table shows the number of days the Ohio River at Cincinnati was above the flood stage of 50 feet for each month during the entire 50 years, together with the totals for each year and for each month.

TABLE 9.—Total number of days with river above 50 feet at Cincinnati, Ohio, 1861 to 1910, inclusive.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.
1861.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1862.....	6	0	0	6	0	0	0	0	0	0	0	0	12
1863.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1864.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1865.....	0	0	5	0	2	0	0	0	0	0	0	0	7
1866.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1867.....	0	7	12	0	0	0	0	0	0	0	0	0	19
1868.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1869.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1870.....	6	0	0	0	0	0	0	0	0	0	0	0	6
1871.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1872.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1873.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1874.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1875.....	0	0	0	0	0	0	0	5	0	0	0	0	5
1876.....	1	0	0	0	0	0	0	0	0	0	0	0	1
1877.....	5	0	0	0	0	0	0	0	0	0	0	0	5
1878.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1879.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1880.....	0	4	0	0	0	0	0	0	0	0	0	0	4
1881.....	0	2	0	0	0	0	0	0	0	0	0	0	2
1882.....	0	9	0	0	0	0	0	0	0	0	0	0	9
1883.....	0	16	0	0	0	0	0	0	0	0	0	0	16
1884.....	0	19	0	0	0	0	0	0	0	0	0	0	19
1885.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1886.....	0	0	0	12	0	0	0	0	0	0	0	0	12
1887.....	0	10	3	0	0	0	0	0	0	0	0	0	13
1888.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1889.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1890.....	0	3	12	0	0	0	0	0	0	0	0	0	15
1891.....	0	8	0	0	0	0	0	0	0	0	0	0	8
1892.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1893.....	0	8	0	0	2	0	0	0	0	0	0	0	10
1894.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1895.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1896.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1897.....	0	6	2	0	0	0	0	0	0	0	0	0	8
1898.....	5	0	7	3	0	0	0	0	0	0	0	0	15
1899.....	0	0	7	2	0	0	0	0	0	0	0	0	9
1900.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1901.....	0	0	0	8	1	0	0	0	0	0	0	0	9
1902.....	0	0	4	0	0	0	0	0	0	0	0	0	4
1903.....	0	0	8	0	0	0	0	0	0	0	0	0	8
1904.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1905.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1906.....	0	0	0	1	0	0	0	0	0	0	0	0	1
1907.....	11	0	11	0	0	0	0	0	0	0	0	0	22
1908.....	0	2	6	4	0	0	0	0	0	0	0	0	12
1909.....	0	4	2	0	0	0	0	0	0	0	0	0	6
1910.....	0	0	3	0	0	0	0	0	0	0	0	0	3
Sums.....	34	98	82	36	5	0	0	5	0	0	0	0	260

TABLE NO. 10.

The table shows the number of days the Ohio River at Cincinnati was above the 40-foot stage for each month during the entire 50 years, together with the totals for each year and for each month.

TABLE 10.—*Total number of days with river above 40 feet at Cincinnati, Ohio, 1861 to 1910, inclusive.*

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	An- nual.
	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1861.....	2	0	0	7	0	0	0	0	0	2	0	0	11
1862.....	10	10	6	15	0	0	0	0	0	0	0	0	41
1863.....	1	1	3	0	0	0	0	0	0	0	0	0	5
1864.....	0	0	0	0	0	0	0	0	0	0	0	5	5
1865.....	0	2	19	6	8	0	0	0	0	0	0	2	37
1866.....	0	0	0	0	0	0	0	0	2	0	0	0	2
1867.....	0	15	19	0	0	0	0	0	0	0	0	0	34
1868.....	3	0	10	2	2	0	0	0	2	0	0	0	19
1869.....	0	0	2	6	0	0	0	0	0	0	0	0	8
1870.....	10	0	2	13	0	0	0	0	0	0	0	0	25
1871.....	0	0	0	0	1	0	0	0	0	0	0	0	1
1872.....	0	0	0	5	0	0	0	0	0	0	0	0	5
1873.....	0	3	0	0	0	0	0	0	0	0	0	4	7
1874.....	6	5	0	6	4	0	0	0	0	0	0	0	21
1875.....	0	0	5	0	0	0	0	9	0	0	0	4	18
1876.....	11	10	1	1	0	0	0	0	0	0	0	0	23
1877.....	9	0	3	0	0	0	0	0	0	0	0	0	12
1878.....	0	0	0	0	0	0	0	0	0	0	0	3	3
1879.....	0	2	0	0	0	0	0	0	0	0	0	2	4
1880.....	3	7	7	3	2	0	0	0	0	0	0	0	22
1881.....	0	9	0	3	0	0	0	0	0	0	0	2	14
1882.....	23	20	6	0	4	0	0	0	0	0	0	0	53
1883.....	0	18	0	9	0	0	0	0	0	0	0	6	33
1884.....	0	25	15	0	0	0	0	0	0	0	0	0	40
1885.....	5	0	0	0	0	0	0	0	0	0	0	0	5
1886.....	0	1	1	16	0	0	0	0	0	0	0	0	18
1887.....	3	28	7	5	0	0	0	0	0	0	0	0	43
1888.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1889.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1890.....	6	13	24	1	7	0	0	0	0	0	0	0	51
1891.....	6	26	10	6	0	0	0	0	0	0	0	0	48
1892.....	2	0	0	6	0	0	0	0	0	0	0	0	8
1893.....	0	14	0	1	11	0	0	0	0	0	0	0	26
1894.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1895.....	5	0	0	0	0	0	0	0	0	0	0	0	5
1896.....	0	0	0	6	0	0	2	2	0	0	0	0	10
1897.....	0	12	14	0	0	0	0	0	0	0	0	0	26
1898.....	16	0	10	5	0	0	0	0	0	0	0	0	31
1899.....	8	0	13	4	0	0	0	0	0	0	0	0	25
1900.....	0	0	0	0	0	0	0	0	0	0	0	1	1
1901.....	0	0	0	10	3	2	0	0	0	0	0	0	15
1902.....	2	2	15	3	0	0	0	0	0	0	0	7	29
1903.....	0	14	19	5	0	0	0	0	0	0	0	0	38
1904.....	4	0	14	5	0	0	0	0	0	0	0	0	23
1905.....	0	0	11	0	6	0	0	0	0	0	0	1	18
1906.....	0	0	1	6	0	0	0	0	0	0	0	0	7
1907.....	19	0	15	0	0	3	0	0	0	0	0	0	37
1908.....	0	9	19	9	6	0	0	0	0	0	0	0	43
1909.....	0	5	8	0	7	0	0	0	0	0	0	0	20
1910.....	8	1	12	0	0	0	0	0	0	0	0	0	21
Sums.....	162	252	291	164	61	5	2	11	4	2	0	37	991

TABLE No. 11.

This table shows the number of days the Ohio River at Cincinnati was below the 10-foot stage for each month during the entire 50 years, together with the totals for each year and for each month.

TABLE 11.—Total number of days with river below 10 feet at Cincinnati, Ohio, 1861–1910, inclusive.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.
1861.....	0	0	0	0	0	12	31	11	22	0	0	0	76
1862.....	0	0	0	0	0	0	8	31	30	31	27	23	150
1863.....	0	0	0	0	4	30	24	31	30	31	22	6	178
1864.....	6	7	0	0	0	11	31	21	3	9	2	0	90
1865.....	0	0	0	0	0	0	9	13	8	25	16	11	82
1866.....	0	0	0	0	5	30	18	22	7	5	1	0	88
1867.....	0	0	0	0	0	1	28	31	30	31	30	15	166
1868.....	0	3	0	0	0	3	31	21	10	20	5	0	93
1869.....	0	0	0	0	0	0	0	22	19	24	23	0	88
1870.....	0	0	0	0	0	2	17	9	26	31	25	1	111
1871.....	14	0	0	0	3	27	31	31	30	31	24	25	216
1872.....	11	9	5	4	8	12	11	23	30	31	17	19	180
1873.....	0	0	0	0	0	23	6	12	25	24	4	0	94
1874.....	0	0	0	0	7	30	29	24	30	31	27	3	181
1875.....	5	4	0	0	6	4	0	1	30	31	6	0	87
1876.....	0	0	0	0	0	15	8	18	12	17	8	7	85
1877.....	0	1	1	0	0	10	11	31	30	31	16	0	131
1878.....	4	0	0	0	0	9	22	17	18	26	4	0	100
1879.....	0	0	0	0	10	25	31	18	24	31	25	7	171
1880.....	0	0	0	0	12	5	14	21	30	31	14	3	130
1881.....	5	0	0	0	2	8	25	31	30	31	6	0	138
1882.....	0	0	0	0	0	0	2	11	0	21	30	6	70
1883.....	0	0	0	0	0	0	2	21	30	24	0	0	77
1884.....	0	0	0	0	0	8	18	27	30	31	30	12	156
1885.....	0	4	4	1	0	4	29	3	12	17	0	0	74
1886.....	0	0	0	0	0	2	6	14	30	31	17	0	100
1887.....	0	0	0	0	3	9	31	31	30	31	30	31	196
1888.....	4	3	0	0	5	19	12	20	2	11	0	0	76
1889.....	0	0	0	0	0	0	0	10	28	24	0	0	62
1890.....	0	0	0	0	0	0	18	21	0	0	0	0	39
1891.....	0	0	0	0	20	0	3	12	17	31	21	0	104
1892.....	0	0	0	0	0	0	10	28	30	31	30	18	147
1893.....	5	0	0	0	0	0	21	31	25	15	18	2	117
1894.....	0	0	0	0	2	11	31	31	26	31	30	11	173
1895.....	5	0	0	0	0	29	28	31	30	31	30	23	207
1896.....	11	0	0	0	10	6	1	0	30	2	1	0	61
1897.....	1	0	0	0	0	6	6	20	30	31	19	0	113
1898.....	0	0	0	0	0	9	25	0	29	22	0	0	85
1899.....	0	0	0	0	0	0	26	24	30	31	30	15	156
1900.....	7	0	0	0	6	16	22	26	30	30	23	9	169
1901.....	4	4	7	0	0	0	4	14	12	31	29	0	105
1902.....	6	8	0	0	4	15	0	18	30	27	27	0	135
1903.....	0	0	0	0	12	0	2	31	22	27	23	21	138
1904.....	0	0	0	0	0	4	8	31	30	31	30	30	164
1905.....	1	7	0	0	0	0	0	3	14	19	0	0	44
1906.....	0	3	0	0	7	3	17	5	16	0	8	0	59
1907.....	0	0	0	0	0	0	0	5	1	18	2	0	26
1908.....	0	0	0	0	0	4	19	24	30	31	30	26	164
1909.....	1	0	0	0	0	0	9	19	30	30	29	23	141
1910.....	2	0	0	0	0	0	5	31	29	24	30	16	137
Sums.....	92	53	17	5	126	402	740	981	1,127	1,205	819	363	5,930

TABLE No. 12.

A correlation is here shown between the precipitation for August, September, and October and the number of days that the river was below 10 feet at Cincinnati, during the same months, for each year of the entire 50 years. This is the usual correlation table. In these tables the correlation coefficient "r" is determined by dividing the sum of column 8 by the square root of the product of the sums of

columns 4 and 7. If the correlation coefficient be 1 in this calculation, there is an exact relation between the two factors, and if  $-1$  there is an exact opposite connection. In this case  $426.74 \times 26,562$  (the sums of columns 4 and 7, respectively)  $= 11,335,067.88$ . The square root of this product is 3,366.76. The sum of column 8 is  $-2,490.8$ . This sum divided by  $3,366.76 = -0.74$ . This is a very high negative coefficient and shows plainly that the smaller the amount of rainfall during August, September, and October the greater the number of days with the river below 10 feet.

It is considered safe to assume that there is a well-defined relation in these cases if "r" is six times the probable error. The probable error

is obtained by the following formula:  $0.674 \frac{1-r^2}{\sqrt{N}}$ . In which "r" is the correlation coefficient and N the number of years under discussion. The probable error here is  $\pm 0.04$ , or only one-eighteenth of "r."

The question might properly be raised as to whether the rainfall during July might have a marked influence on the low-water days in August, September, and October, as discussed in this table. But a similar correlation table worked out for the rainfall for July, August, September, and October, and the number of days with the river below 10 feet in August, September, and October, gives a correlation coefficient of  $-0.73$ , or very slightly less than with July rainfall omitted.

TABLE 12.—Correlation of precipitation and days with river below 10 feet, in August, September, and October, Ohio River, Cincinnati, Ohio, 1861 to 1910, inclusive.

Years.	Precipitation.			Days.			Product of columns 3 and 6.
	Precipitation.	Departure.	Square of column 3.	Days.	Departure.	Square of column 6.	
1	2	3	4	5	6	7	8
	Inches.	Inches.		Days.	Days.		
1861.....	11.4	+2.7	7.29	33	-33	1,089	- 89.2
1862.....	5.0	-3.7	13.69	92	+26	676	- 96.2
1863.....	8.7	0	0	92	+26	676	0
1864.....	12.7	+4.0	16.00	33	-33	1,089	- 132.0
1865.....	10.2	+1.5	2.25	46	-20	400	- 30.0
1866.....	17.2	+8.5	72.25	34	-32	1,024	- 272.0
1867.....	6.6	-2.1	4.41	92	+26	676	- 54.6
1868.....	13.9	+5.2	27.04	51	-15	225	- 78.0
1869.....	8.2	-0.5	.25	65	- 1	1	+ 0.5
1870.....	7.4	-1.3	1.69	66	0	0	0
1871.....	7.5	-1.2	1.44	92	+26	676	- 31.2
1872.....	7.2	-1.5	2.25	84	+18	324	- 27.0
1873.....	10.6	+1.9	3.61	61	- 5	25	- 9.5
1874.....	5.6	-3.1	9.61	85	+19	364	- 58.9
1875.....	7.8	-0.9	.81	62	- 4	16	+ 3.6
1876.....	11.5	+2.8	7.84	47	-19	361	- 53.2
1877.....	5.9	-2.8	7.84	92	+26	676	- 72.8
1878.....	10.1	+1.4	1.96	61	- 5	25	- 7.0
1879.....	9.7	+1.0	1.00	73	+ 7	49	+ 7.0
1880.....	9.5	+0.8	.64	82	+16	256	+ 12.8
1881.....	8.8	+0.1	.01	92	+26	676	+ 2.6
1882.....	10.1	+1.4	1.96	32	-34	1,156	- 47.6
1883.....	9.3	+0.6	.36	75	+ 9	81	+ 5.4
1884.....	6.8	-1.9	3.61	88	+22	284	- 41.8
1885.....	12.0	+3.3	10.89	32	-34	1,156	- 112.2
1886.....	8.1	-0.6	0.36	75	+ 9	81	- 5.4
1887.....	5.4	-3.3	10.89	92	+26	676	- 85.8
1888.....	14.3	+5.6	31.36	33	-33	1,089	- 184.8
1889.....	7.4	-1.3	1.69	62	- 4	16	+ 5.2



**TABLE 12.—Correlation of precipitation and days with river below 10 feet in August, September, and October, Ohio River, Cincinnati Ohio, 1861 to 1910, inclusive—Continued.**

Years.	Precipitation.			Days.			Product of columns 3 and 6.
	Precipitation.	Departure.	Square of column 3.	Days.	Departure.	Square of column 6.	
1	2	3	4	5	6	7	8
	<i>Inches.</i>	<i>Inches.</i>		<i>Days.</i>	<i>Days.</i>		
1800.....	14.6	+5.9	34.81	21	-45	2,025	- 265.5
1891.....	6.5	-2.2	4.84	60	- 6	36	+ 13.2
1892.....	6.5	-2.2	4.84	89	+23	529	- 50.6
1893.....	8.7	0	0	71	+ 5	25	0
1894.....	7.2	-1.5	2.25	88	+22	484	- 33.0
1895.....	5.1	-3.6	12.96	92	+26	676	- 93.6
1896.....	10.3	+1.6	2.56	32	-34	1,156	- 54.4
1897.....	3.8	-4.9	24.01	81	+15	225	- 73.5
1898.....	10.9	+2.2	4.84	51	-15	225	- 33.0
1899.....	7.3	-1.4	1.96	85	+19	361	- 26.6
1900.....	6.8	-1.9	3.61	86	+20	400	- 38.0
1901.....	6.4	-2.3	5.29	57	- 9	81	+ 20.7
1902.....	7.5	-1.2	1.44	75	+ 9	81	- 10.8
1903.....	5.5	-3.2	10.24	80	+14	196	- 44.8
1904.....	4.7	-4.0	16.00	92	+26	676	- 104.0
1905.....	12.5	+3.8	14.44	36	-30	900	- 114.0
1906.....	10.9	+2.2	4.84	21	-45	2,025	- 99.0
1907.....	7.7	-1.0	10.00	24	-42	1,764	+ 42.0
1908.....	4.3	-4.4	19.36	85	+19	361	- 83.6
1909.....	7.1	-1.6	2.56	79	+13	169	- 20.8
1910.....	10.4	+1.7	2.89	84	+18	324	+ 30.6
Sums.....			426.74			26,562	-2,490.8
Means.....	8.7			66			

The correlation coefficient is  $-0.74$ . The probable error is  $\pm 0.04$ .

**TABLE 13.**

In Table 13 the correlation coefficient is determined for the precipitation over the Ohio watershed above Cincinnati, and the number of days that the river was above 40 feet at Cincinnati, during the months of February and March, for the 50 years. The effect of the precipitation upon the flood conditions is more remarkable, if possible, than upon the low-water days as indicated in Table 12, because the correlation coefficient is 0.80 in Table 13. This is 27 times the probable error. This table alone should be very conclusive evidence that the high-water conditions in the Ohio Valley, during the months when there are the greatest number of high-water days, are controlled by the precipitation and nothing else.

By obtaining the correlation coefficient for the different 25-year periods from this table the fact that the cutting off of the forests does not make increased flood conditions is plainly established. The correlation coefficient for the 25 years from 1861 to 1885, inclusive, is 0.805, and for the 25 years from 1886 to 1910, inclusive, is 0.804, a difference much less than the probable error. This means that the tendency to cause the water to rise above 40 feet by the same precipitation has been no greater during the last 25 years than during the preceding 25 years, or at least by a value too small to be calculated by the most approved method of correlation.

TABLE 13.—*Precipitation and days with river above 40 feet in February and March, Ohio River, Cincinnati, Ohio, 1861 to 1910, inclusive.*

Years.	Precipitation.			Days.			Product of columns 3 and 6.
	Precipitation.	Departure.	Square of column 3.	Days.	Departure.	Square of column 6.	
	2	3	4	5	6	7	8
1	2	3	4	5	6	7	8
	Inches.	Inches.		Days.	Days.		
1861	4.3	−2.7	7.29	0	−11	121	+ 29.7
1862	7.7	+0.1	.49	16	+ 5	25	+ 0.5
1863	7.1	+0.1	.01	4	− 7	49	− 0.7
1864	4.0	−3.0	9.00	0	−11	121	+ 33.0
1865	7.4	+0.4	.16	21	+10	100	+ 4.0
1866	6.2	−0.8	.64	0	−11	121	+ 8.8
1867	10.0	+3.0	9.00	34	+23	529	+ 69.0
1868	6.5	−0.5	.25	10	− 1	1	+ 0.5
1869	7.1	+0.1	.01	2	− 9	81	− 0.9
1870	7.3	+0.3	.09	2	− 9	81	− 2.7
1871	5.3	−1.7	2.89	0	−11	121	+ 18.7
1872	3.4	−3.6	12.96	0	−11	121	+ 39.6
1873	6.7	−0.3	.09	3	− 8	64	− 2.4
1874	7.6	+0.6	.36	5	− 6	36	− 3.6
1875	5.8	−1.2	1.44	5	− 6	36	+ 7.2
1876	6.3	−0.7	.49	11	0	0	0
1877	6.0	−1.0	1.00	3	− 8	64	+ 8.0
1878	4.7	−2.3	5.92	0	−11	121	+ 25.3
1879	7.1	+0.1	.01	2	− 9	81	− 0.9
1880	8.0	+1.0	1.00	14	+ 5	25	+ 5.0
1881	7.2	+0.2	.04	9	− 2	4	− 0.4
1882	10.1	+3.1	9.61	26	+15	225	+ 46.5
1883	10.2	+3.2	10.24	18	+ 7	49	+ 22.4
1884	10.2	+3.2	10.24	40	+29	841	+ 92.8
1885	3.3	−3.7	13.69	0	−11	121	+ 40.7
1886	5.1	−1.9	3.61	2	− 9	81	+ 17.1
1887	9.4	+2.4	5.76	35	+24	576	+ 57.6
1888	6.1	−0.9	.81	0	−11	121	+ 9.9
1889	2.9	−4.1	16.81	0	−11	121	+ 45.1
1890	12.3	+5.3	28.09	37	+26	676	+ 137.8
1891	10.0	+3.0	9.00	36	+25	625	+ 75.0
1892	6.1	−0.9	.81	0	−11	121	+ 9.9
1893	7.4	+0.4	.16	14	+ 3	9	+ 1.2
1894	5.9	−1.1	1.21	0	−11	121	+ 12.1
1895	3.1	−3.9	15.21	0	−11	121	+ 42.9
1896	6.7	−0.3	.09	0	−11	121	+ 3.3
1897	11.3	+4.3	18.49	26	+15	225	+ 64.5
1898	9.3	+2.3	5.29	10	− 1	1	− 2.3
1899	8.4	+1.4	1.96	13	+ 2	4	+ 2.8
1900	5.4	−1.6	2.56	0	−11	121	+ 17.6
1901	3.7	−3.3	10.89	0	−11	121	+ 36.3
1902	4.2	−2.8	7.84	17	+ 6	36	− 16.8
1903	9.9	+2.9	8.41	33	+22	484	+ 63.8
1904	8.0	+1.0	1.00	14	+ 3	9	+ 3.0
1905	5.2	−1.8	3.21	11	0	0	0
1906	6.9	−0.1	.01	1	−10	100	+ 1.0
1907	7.0	0	0	15	+ 4	16	0
1908	10.6	+3.6	12.96	28	+17	289	+ 61.2
1909	8.9	+1.9	3.61	13	+ 2	4	+ 3.8
1910	7.3	+0.3	.09	13	+ 2	4	+ 0.6
Sums			254.80			7,245	+1,092.3
Means	7.0			11			

The correlation coefficient is 0.80. The probable error is ±0.03.

TABLE 14.

In this table the same calculation is made for the relation between the precipitation in February and March and the number of days above 50 feet, or flood stage. One would not expect this correlation coefficient to be so high as in Table 13, even if the relation is actually closer, because of the great number of years when the river did not

rise above 50 feet during these two months. And yet in this case "r" equals 0.74; high enough to make the relation well marked. The determination of the correlation coefficient in this table for each of the 25-year periods shows that the tendency to produce flood days with the same rainfall is slightly less during the last 25 years than during the preceding, although by a value too small to be considered, being about 0.3 per cent.

TABLE 14.—*Precipitation and days with river above 50 feet in February and March, Ohio River, Cincinnati, Ohio, 1861 to 1910, inclusive.*

Years.	Precipitation.			Days.			Product of columns 3 and 6.
	Precipitation.	Departure.	Square of column 3.	Days.	Departure.	Square of column 6.	
	2	3	4	5	6	7	
1	Inches.	Inches.		Days.	Days.		
1861	4.3	-2.7	7.29	0	-4	16	+ 10.8
1862	7.7	+0.7	.49	0	-4	16	- 2.8
1863	7.1	+0.1	.01	0	-4	16	- 0.4
1864	4.0	-3.0	9.00	0	-4	16	+ 12.0
1865	7.4	+0.4	.16	5	+1	1	+ 0.4
1866	6.2	-0.8	.64	0	-4	16	+ 3.2
1867	10.0	+3.0	9.00	19	+15	225	+ 45.0
1868	6.5	-0.5	.25	0	-4	16	+ 2.0
1869	7.1	+0.1	.01	0	-4	16	- 0.4
1870	7.3	+0.3	.09	0	-4	16	- 1.2
1871	5.3	-1.7	2.89	0	-4	16	+ 6.8
1872	3.4	-3.6	12.96	0	-4	16	+ 14.4
1873	6.7	-0.3	.09	0	-4	16	+ 1.2
1874	7.6	+0.6	.36	0	-4	16	- 2.4
1875	5.8	-1.2	1.44	0	-4	16	+ 4.8
1876	6.3	-0.7	.49	0	-4	16	+ 2.8
1877	6.0	-1.0	1.00	0	-4	16	+ 4.0
1878	4.7	-2.3	5.92	0	-4	16	+ 9.2
1879	7.1	+0.1	.01	0	-4	16	- 0.4
1880	8.0	+1.0	1.00	4	0	0	0
1881	7.2	+0.2	.04	2	-2	4	- 0.4
1882	10.1	+3.1	9.61	9	+5	25	+ 15.5
1883	10.2	+3.2	10.24	16	+12	144	+ 38.4
1884	10.2	+3.2	10.24	19	+15	225	+ 48.0
1885	3.3	-3.7	13.69	0	-4	16	+ 14.8
1886	5.1	-1.9	3.61	0	-4	16	+ 7.6
1887	9.4	+2.4	5.76	13	+9	81	+ 21.6
1888	6.1	-0.9	.81	0	-4	16	+ 3.6
1889	2.9	-4.1	16.81	0	-4	16	+ 16.4
1890	12.3	+5.3	28.09	15	+11	121	+ 58.3
1891	10.0	+3.0	9.00	8	+4	16	+ 12.0
1892	6.1	-0.9	.81	0	-4	16	+ 3.6
1893	7.4	+0.4	.16	8	+4	16	+ 1.6
1894	5.9	-1.1	1.21	0	-4	16	+ 4.4
1895	3.1	-3.9	15.21	0	-4	16	+ 15.6
1896	6.7	-0.3	.09	0	-4	16	+ 1.2
1897	11.3	+4.3	18.49	8	+4	16	+ 17.2
1898	9.3	+2.3	5.29	7	+3	9	+ 6.9
1899	8.4	+1.4	1.96	7	+3	9	+ 4.2
1900	5.4	-1.6	2.56	0	-4	16	+ 6.4
1901	3.7	-3.3	10.89	0	-4	16	+ 13.2
1902	4.2	-2.8	7.84	4	0	0	0
1903	9.9	+2.9	8.41	8	+4	16	+ 11.6
1904	8.0	+1.0	1.00	0	-4	16	- 4.0
1905	5.2	-1.8	3.21	0	-4	16	+ 7.3
1906	6.9	-0.1	.01	0	-4	16	+ 0.4
1907	7.0	0	0	11	+7	49	0
1908	10.6	+3.6	12.96	8	+4	16	+ 14.4
1909	8.9	+1.9	3.61	6	+2	4	+ 3.8
1910	7.3	+0.3	.09	3	-1	1	- 0.3
Sum.			254.80			1,458	+452.3
Mean.	7.0			4			

The correlation coefficient is 0.74.

TABLE 15.

In this table the years, precipitation, and river stages are grouped for each difference in precipitation amounting to 1 inch for February and March. This table shows several important facts, among them being:

(1) In only one year has the river reached the flood stage during these months when the precipitation was less than the normal, 7 inches.

(2) The most marked increase in flood days comes with the increase of the precipitation from between 9 and 10 inches to between 10 and 11 inches.

(3) The average rate of increase in number of flood days with each increase of 1 inch in the precipitation is 2.5; this calculation is made for years when the precipitation was above 7 inches.

TABLE 15.—*Precipitation and days with river above 50 feet in February and March, Ohio River, Cincinnati, Ohio, 1861 to 1910, inclusive.*

Precipitation between—	Years.	Precipitation.	Days.	Change.
2.9 and 3.9 inches.....	1872	3.4	0	.....
	1885	3.3	0	.....
	1889	2.9	0	.....
	1895	3.1	0	.....
	1901	3.7	0	.....
4 and 4.9 inches.....	1861	4.3	0	.....
	1864	4.0	0	.....
	1878	4.7	0	.....
	1902	4.2	4	.....
5 and 5.9 inches.....	1871	5.3	0	.....
	1875	5.3	0	.....
	1886	5.1	0	.....
	1894	5.9	0	.....
	1900	5.4	0	.....
6 and 6.9 inches.....	1905	5.2	0	.....
	1866	6.2	0	.....
	1868	6.5	0	.....
	1873	6.7	0	.....
	1876	6.3	0	.....
	1877	6.0	0	.....
	1888	6.1	0	.....
	1892	6.1	0	.....
	1896	6.7	0	.....
	1906	6.9	0	.....
7 and 7.9 inches.....	1862	7.7	0	.....
	1863	7.1	0	.....
	1865	7.4	5	.....
	1869	7.1	0	.....
	1870	7.3	0	.....
	1874	7.6	0	.....
	1879	7.1	0	.....
	1881	7.2	2	.....
	1893	7.4	8	.....
	1907	7.0	11	.....
	1910	7.3	3	.....
Mean.....			2	.....
8 and 8.9 inches.....	1880	8.0	4	.....
	1899	8.4	7	.....
	1904	8.0	0	.....
	1906	8.9	9	.....
Mean.....			5	3

**TABLE 15.**—*Precipitation and days with river above 50 feet in February and March, Ohio River, Cincinnati, Ohio, 1861 to 1910, inclusive—Continued.*

Precipitation between—	Years.	Precipitation.	Days.	Change.
9 and 9.9 inches.....	1887 1898 1903	9.4 9.3 9.9	13 7 8	..... ..... .....
Mean.....			9	4
10 and 10.9 inches.....	1867 1882 1883 1884 1891 1908	10.0 10.1 10.2 10.2 10.0 10.6	19 9 16 19 8 8	..... ..... ..... ..... ..... .....
Mean.....			13	4
11 inches or more.....	1890 1897	12.3 11.3	15 8	..... .....
Mean.....			12	—1
Mean change.....				2.5

**TABLE No. 16.**

This table groups the data when the rainfall was above the normal for February and March, by 10-year and 25-year periods, and shows plainly that instead of a tendency toward increase of flood days in recent years there is actually a decrease, with the same precipitation.

As shown by the last sentence in the discussion of Table 15, the average increase in flood days is 2.5 with each increase in precipitation of 1 inch. Then if 8.2 inches of rain from 1861 to 1885, inclusive, caused 6.5 flood days each year, the rainfall of 9.2 inches from 1886 to 1910, inclusive, should have caused 2.5 days more or 9 flood days each year. But, because the tendency to flood conditions is less, the increase of 1 inch of rain produced an increase of only 1.6 flood days per year.

Applying the same average increase of 2.5 days for each increase of 1 inch in rainfall, or 0.25 day for each increase of 0.1 inch of rain, it will be seen that the number of flood days in the 10 years, 1901 to 1910, inclusive, is exactly the same as the flood days in the 10 years, 1861 to 1870, inclusive, if the difference in rainfall is taken into consideration, and is 2.75 days less than was produced in the 10 years, 1881 to 1890, inclusive, after making allowance for the difference in rainfall.

TABLE 16.—*Precipitation and days with river above 50 feet during February and March, by 10-year periods, Ohio River, Cincinnati, Ohio, 1861–1910, inclusive.*

Year.	Year.	Precipitation.	Days.
1861 to 1870, inclusive.....	1862	7.7	0
	1863	7.1	0
	1865	7.4	5
	1869	7.1	0
	1870	7.3	0
	1867	10.0	19
Mean.....		7.8	4
1871 to 1880, inclusive.....	1874	7.6	0
	1879	7.1	0
	1880	8.0	4
Mean.....		7.6	1
1881 to 1890, inclusive.....	1881	7.2	2
	1887	9.4	13
	1882	10.1	9
	1883	10.2	16
	1884	10.2	19
	1890	12.3	15
Mean.....		9.9	12
1891 to 1900, inclusive.....	1893	7.4	8
	1899	8.4	7
	1898	9.3	7
	1891	10.0	8
	1897	11.3	8
Mean.....		9.3	8
1901 to 1910, inclusive.....	1910	7.3	3
	1907	7.0	11
	1904	8.0	0
	1906	8.9	9
	1903	9.9	8
	1908	10.6	8
Mean.....		8.6	6
Mean, 1861 to 1885, inclusive.....		8.2	6.5
Mean, 1886 to 1910, inclusive.....		9.2	8.1

TABLE No. 17.

In Table 17 the average rainfall and average number of days with the river below 10 feet in August, September, and October is tabulated for differences in rainfall amounting to 1 inch. This shows that the average increase in low-water days with each decrease of 1 inch of rain is 7.

TABLE 17.—*Average precipitation and days with river below 10 feet for August, September, and October for each inch of rain, Ohio River, Cincinnati, Ohio, 1861 to 1910, inclusive.*

Precipitation—	Mean precipitation.	Mean days.	Change.
Below 5 inches.....	4.3	86	.....
Between 5 and 6 inches.....	5.4	89	+ 3
Between 6 and 7 inches.....	6.6	79	—10
Between 7 and 8 inches.....	7.4	72	— 7
Between 8 and 9 inches.....	8.5	79	+ 7
Between 9 and 10 inches.....	9.5	77	— 2
Between 10 and 11 inches.....	10.4	49	—28
Above 11 inches.....	13.3	36	—13
Mean.....			— 7

TABLE NO. 18.

In Table 18 the average rainfall and average number of days with the water below 10 feet in August, September, and October is given for each 10-year and each 25-year period. Remembering that the increase in low-water days amounts to an average of 7 a year with each decrease in the rainfall of 1 inch, it will be seen at once that the number of low-water days during the 10 years from 1901 to 1910, inclusive, were less than in any of the preceding 10-year periods, taking into the account the difference in rainfall. Also that during the last 25 years the average number of low-water days is 9.1 less than would have been produced in the first 25 years with the same amount of rainfall. Or, the tendency to produce low-water conditions in the Ohio River has been 14 per cent less during the 25 years from 1886 to 1910, inclusive, than during the 25 years from 1861 to 1885, inclusive, with the same rainfall, as calculated during the low-water months of August, September, and October.

TABLE 18.—*Average precipitation and number of days with river below 10 feet for August, September, and October, by 10-year and 25-year periods, Ohio River, Cincinnati, Ohio, 1861-1910, inclusive.*

Year.	Precipitation.	Days.
1861 to 1870.....	10.1	60
1871 to 1880.....	8.5	74
1881 to 1890.....	9.7	60
1891 to 1900.....	7.3	74
1901 to 1910.....	7.7	63
1861 to 1885.....	9.3	66
1886 to 1910.....	8.0	66



## EXPLANATION OF CHARTS.

*Chart 1.*—Indicates the location of the seven precipitation stations that were used in obtaining the precipitation for the Ohio watershed above Cincinnati.

*Chart 2.*—The influence of the rainfall upon the number of low-water days during the driest period of the year is plainly shown by this chart.

*Chart 3.*—The relation between the precipitation and number of high-water days during the period of highest water is well indicated. Also that an equal amount of precipitation has no greater tendency to cause an increase in the number of high-water days during the latter part of the period than during the earlier part.

*Chart 4.*—This chart shows that whenever the precipitation for February and March was 1 inch or more above the normal the number of days with the water above 40 feet was always greater than the normal, with one exception. Also that when the precipitation was more than 2 inches above the normal, the number of days was much above the normal, with one or two exceptions. Further, that when the precipitation was below the normal the number of days was always less than the normal, with one exception. The line of dots on the — 11 days' line indicate no days with the river above 40 feet, the average number of days being 11 per year.

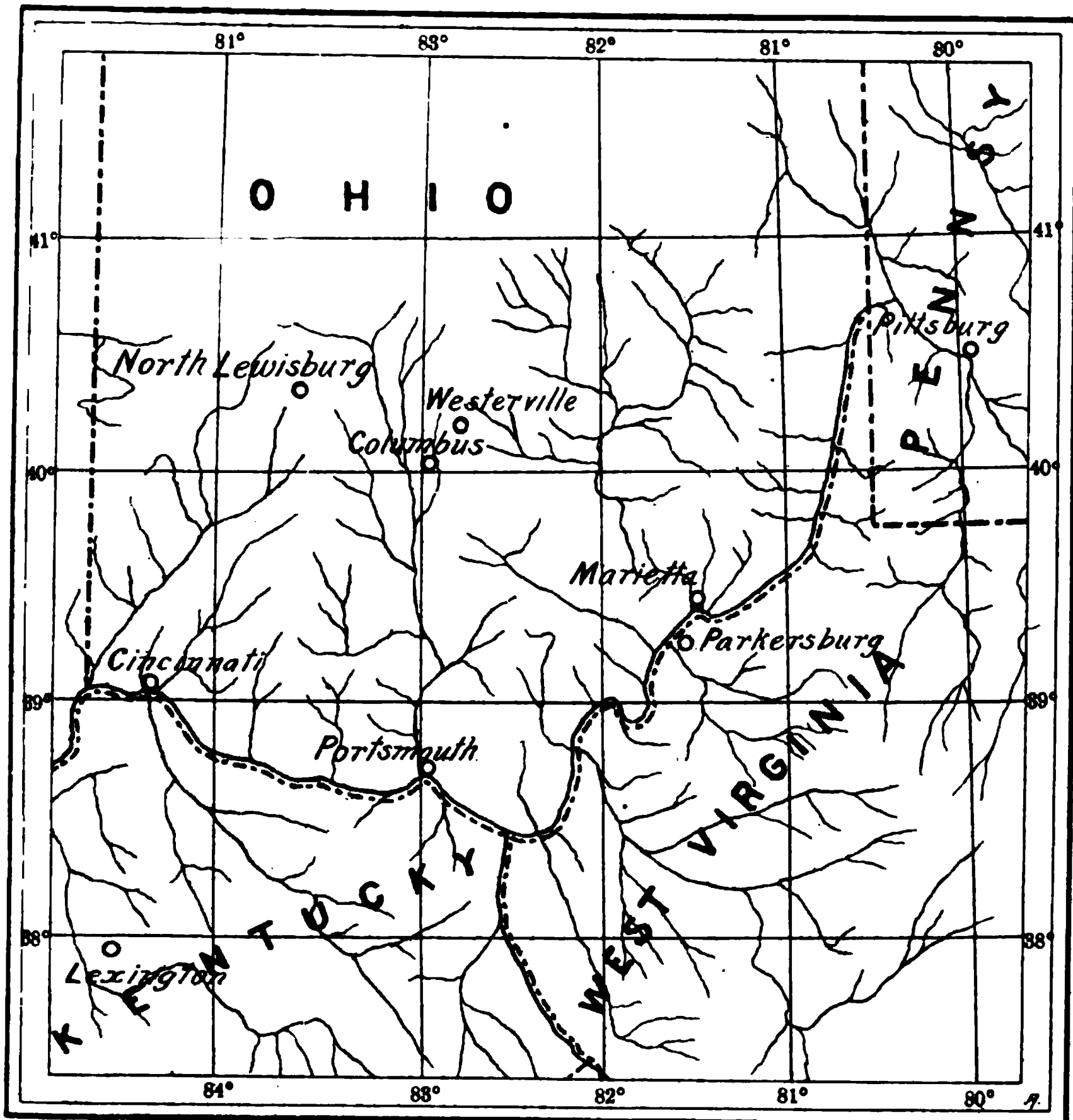


CHART 1.—Location of precipitation stations.

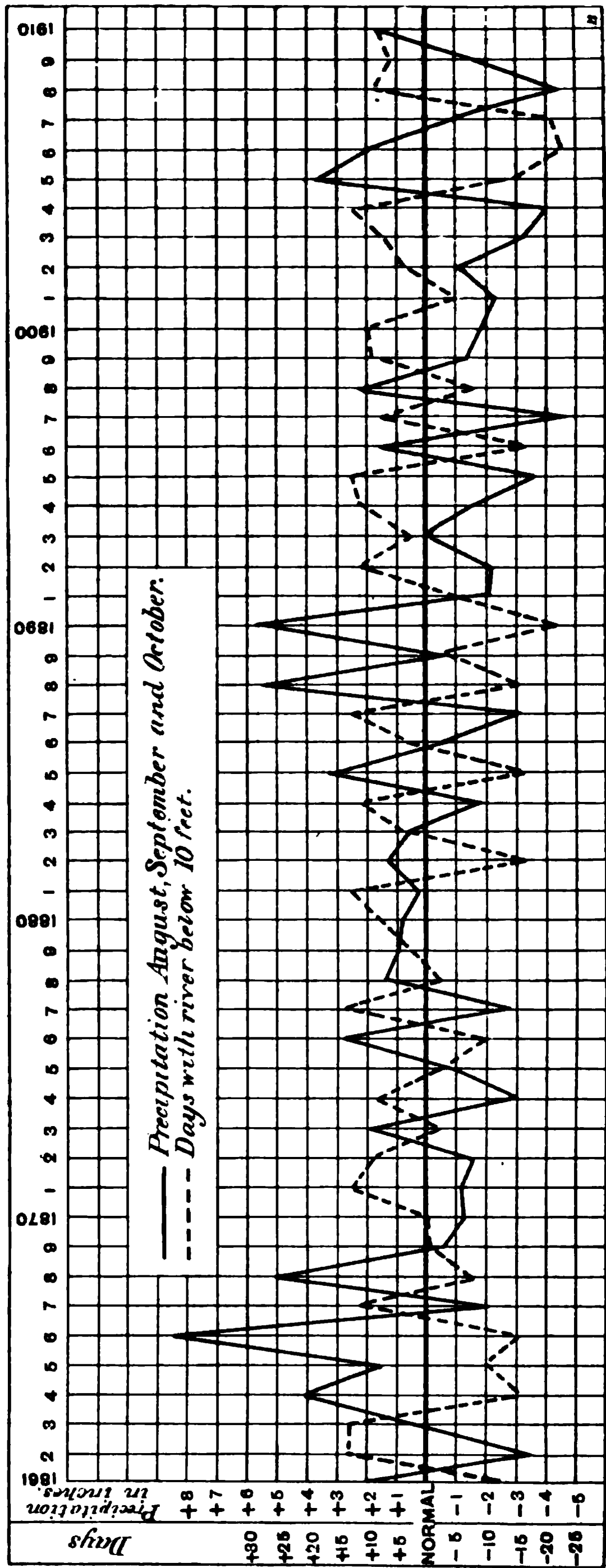


CHART 2.—Relation between precipitation and the number of low-winter days during the driest period of the year.

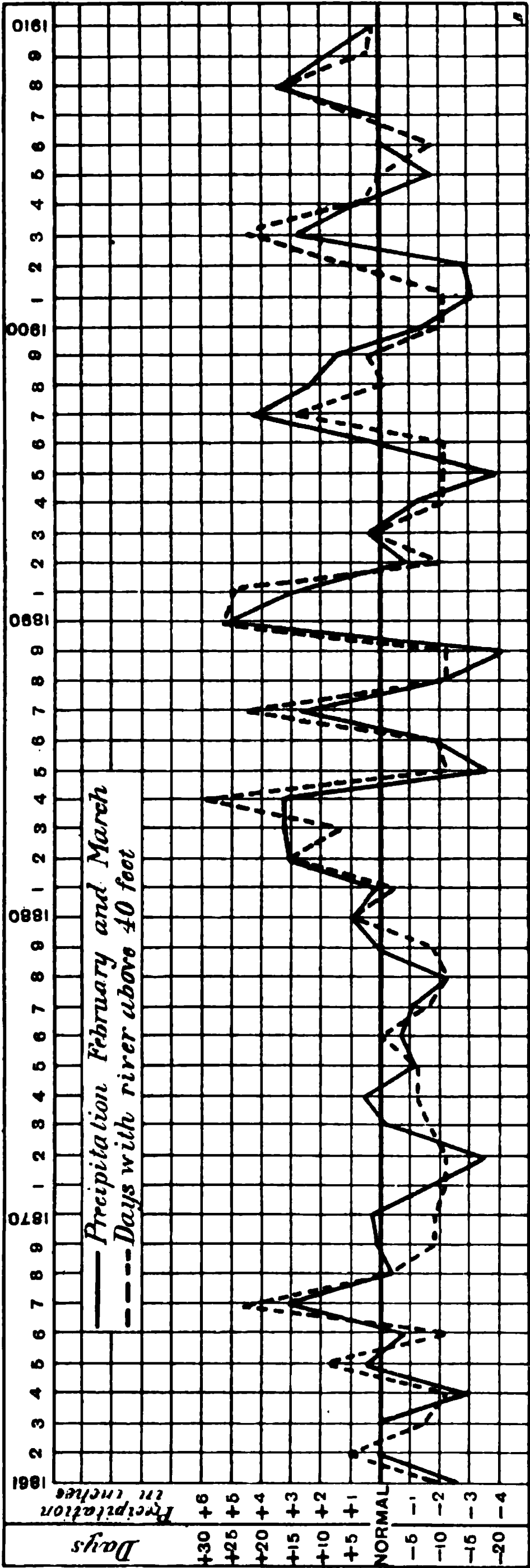


CHART 3.—Relation between precipitation and the number of high-water days during the period of highest water.



**CHART 4.—Departures from normal precipitation during February and March and number of days with the river above 40 feet.**











Bulletin No. 41.—W. B. No. 473.

Issued February 27, 1912.

U. S. DEPARTMENT OF AGRICULTURE.

WEATHER BUREAU.

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# FORECASTING FROST IN THE NORTH PACIFIC STATES.

BY

EDWARD A. BEALS,

DISTRICT FORECASTER.

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Prepared under direction of WILLIS L. MOORE, Chief U. S. Weather Bureau.

WASHINGTON:  
GOVERNMENT PRINTING OFFICE.  
1912.

Harvard College Library

MAR 20 1912

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## LETTER OF TRANSMITTAL.

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UNITED STATES DEPARTMENT OF AGRICULTURE,  
WEATHER BUREAU, OFFICE OF THE CHIEF,  
*Washington, D. C., December 2, 1911.*

The honorable SECRETARY OF AGRICULTURE.

SIR: I have the honor to transmit herewith a paper entitled "Forecasting Frost in the North Pacific States," which has been prepared by Mr. Edward A. Beals, district forecaster of the Weather Bureau.

The paper describes the evolution of the system of frost warnings for the protection of fruit in Washington, Oregon, and Idaho, and contains detailed reports of the conditions under which warnings were issued during the critical season in the spring of 1911 for the fruit districts of Boise, Lewiston, Rogue River Valley, and Yakima Valley. It discusses the meteorological conditions which afford an indication of the probable occurrence of frost and on which warnings may be based. The paper is accompanied by three illustrations showing Weather Bureau equipment for observing temperature conditions, sketches of the four fruit districts mentioned, five weather maps showing the conditions preceding frost, and a chart of composite thermograph curves.

It is thought that the paper contains valuable information to the fruit growers in the States named, and it is therefore recommended that an edition of 2,500 copies be issued for distribution in those regions.

Very respectfully, your obedient servant,

WILLIS L. MOORE,  
*Chief United States Weather Bureau.*

Approved.

JAMES WILSON, *Secretary.*



# FORECASTING FROST IN THE NORTH PACIFIC STATES

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By EDWARD A. BEALS.

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*Historical.*—According to Boussingault, the celebrated French chemist, smudges have been used for centuries on the plains of Cusco on still clear nights by Indians to retard the loss of heat from the soil, and it is thought that the same or similar methods have been used in Europe for an equally long period. It is only in recent years, however, that the matter of frost protection has been scientifically investigated, and for literature on the subject the reader is referred to Farmers' Bulletin No. 104, Bulletin T, published by the Weather Bureau, and to various articles in the Monthly Weather Review.

Fruit raising in the north Pacific States has increased enormously in the last few years, and the number of trees that will come into bearing in the next five or six years will increase the acreage at least tenfold. In the early days of the industry the principal crop was prunes, and the large orchards were mostly in the humid sections of Oregon and Washington. There were very few large apple and peach orchards, and those in bearing were nearly all located where the air drainage was good and the losses by spring frosts were infrequent. In the case of prunes many of the growers believed that when they had short crops the damage was done by cold rains during the blossoming period, which prevented the bees from carrying pollen to the stigmata, and the fruit did not set on that account, rather than because of injury by frost.

For these reasons very few growers a few years ago made any attempt to protect their orchards from frost, and those that did were not very successful, as their methods were crude, and where the necessity was greatest the orchards were badly located and the task was almost hopeless from the start. Frost warnings were issued by the Weather Bureau during this time, although very little attention was paid to them, as foreknowledge of frost is of practically no benefit to the horticulturist unless he is prepared to protect his crop from threatened injury.

In 1907 Mr. P. J. O'Gara, one of the scientific assistants in the Bureau of Plant Industry, was sent to the Rogue River Valley to study the pear blight, which was making inroads among the pear



and Spitzenberg apple trees in that section of the country. He quickly realized that the fruit growers were losing much more fruit by spring frosts than they were willing to acknowledge, and being familiar with orchard-heating methods in California, he soon induced a number of orchardists to adopt similar methods in the Rogue River Valley. The plan was so successful the first year that it was tried the next on a fairly large scale and with even greater success. In the meanwhile a few orchardists in other important sections had taken up this work, and by the spring of 1910 the movement had obtained large proportions in four important fruit centers, viz, Rogue River Valley, Yakima Valley, Lewiston orchard district, and the Boise orchard district.

As soon as an orchardist was prepared to heat his orchard the question of accurate frost warnings became of paramount importance, and as the number increased the question became accentuated. The owners and managers of these orchards had gone to the expense of thousands of dollars for material to insure their crops from damage by frost, and they were not satisfied with a warning classified as a light or a heavy frost, where in the one case the minimum temperature in a standard thermometer shelter was expected to remain above 32° and in the other sink below that point. They want to know just how cold it will get and just when it will be necessary to start their fires. They also want this information as far ahead of each impending frost as possible.

The district forecaster had been making forecasts of light and heavy frosts, basing his verifications upon thermometer readings at Weather Bureau reporting stations; those for the Rogue River Valley being based upon reports received from Roseburg, Marshfield, and Siskiyou, all some distance away and where the thermometers were exposed in shelters at different elevations above the ground; those for Boise upon reports from readings taken in an instrument shelter on the roof, 78 feet above the ground; those at Lewiston over sod, 10 feet above the ground; and those for Yakima from the station at Walla Walla with thermometers located on the roof, 62 feet above the ground.

These irregular exposures which in some cases were many miles from the place where we were to look for accuracy in results made it necessary to weigh the forecasts by further estimates as to the differences that would probably prevail between the temperatures at the reporting stations and those in the orchards being protected. We could obtain average differences by studying the cooperative observer's records at near-by stations, but these were unsatisfactory, and it was soon found that to get best results we had to put stations in the heart of the orchard districts, and then there were large differences to be calculated at places not very far apart.

Accordingly, early in 1911 the Chief of the Weather Bureau authorized the writer to make an investigation of the subject with a view to localizing the work and improving the forecasts. The foregoing four localities were selected for the first year's work and a number of "key" stations were established in the heart of the different districts. (See Fig. I, Fig. II, and Fig. III.) It was necessary to employ temporary observers to look after the "key" stations and to send a trained man to North Yakima to look after the work in that valley. In the Rogue River Valley we were fortunate in securing the services of Mr. P. J. O'Gara, who had made a special study of the frost conditions in that section and was familiar with the topography in every orchard for many miles around Medford, Oreg.

FIG. I.--"Key" station, Boise, Idaho.

An abstract of the reports from the different localized centers follows:

*Medford* (by Mr. P. J. O'Gara). (See Diagram A.)—We have had a hard pull of it, but in every case where the growers had properly prepared for the fight they have won out. A careful examination of the orchards above the valley floor shows scarcely any damage excepting in some peaches and the Bosc pears, which are most easily injured. However, even the Bosc pears will have quite a good crop. On the valley floor, especially during the mornings of April 14, 15, and 29, the fight was a hard one. However, the lowest drop of 22° to 24° was for such a short time that, in the main, 25° and 26° were the temperatures

against which we were contending. The fact that there was little or no wind movement was a tremendous advantage to those heating the orchards. The loss

FIG. II.—“Key” station, Lewiston Orchards, Lewiston, Idaho.

FIG. III.—“Key” station, Parkers Bottom, Yakima Valley, Wash.

on the valley floor is very light, because practically all the growers who had anything to save did their work. Two or three were not fully equipped, but it

was not because they had not been advised better. They had their own way about it in the matter of the number of fires, and now they see their folly. At this time it looks as though we are to have a better pear crop than last year.

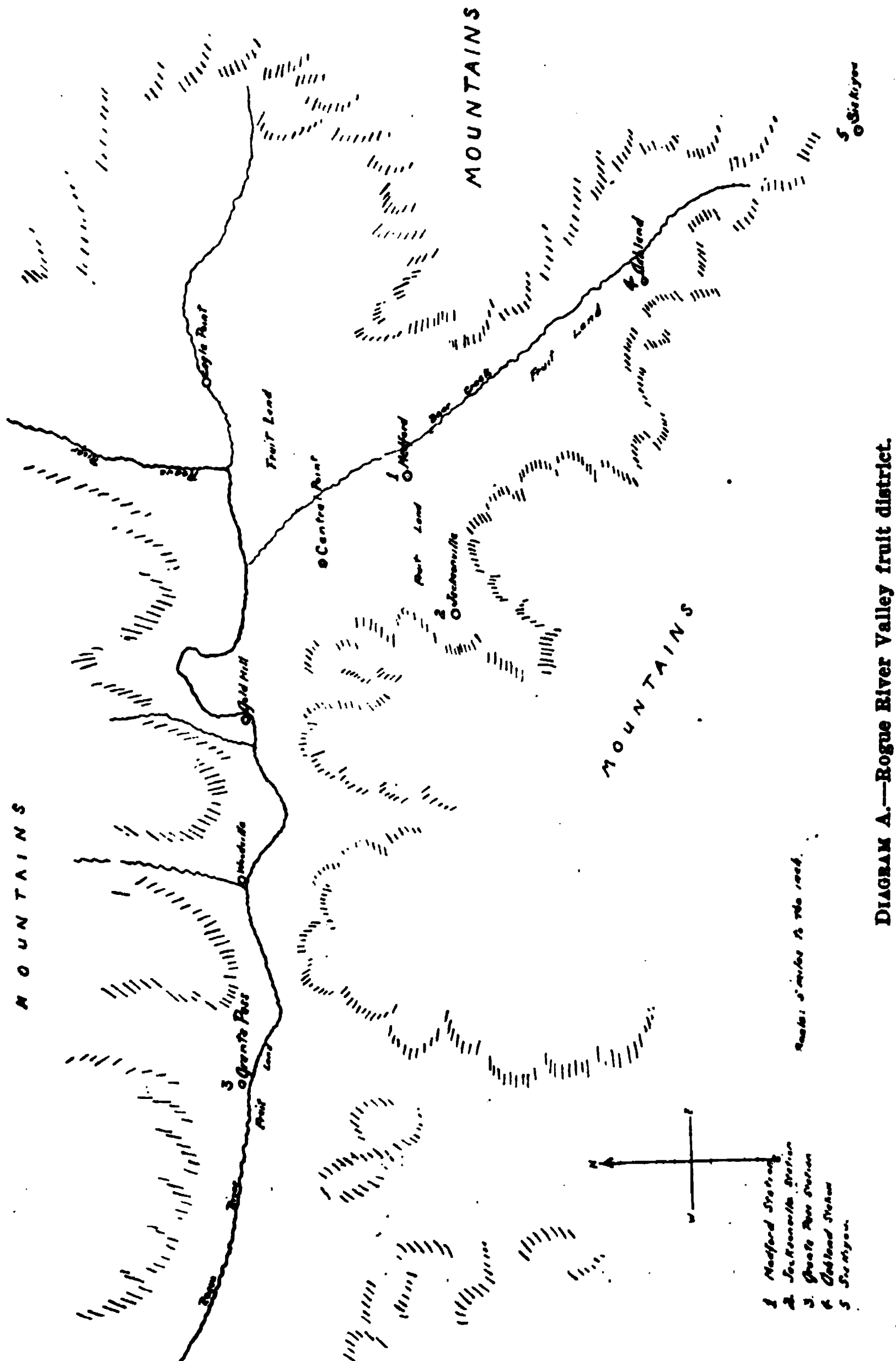


DIAGRAM A.—Rogue River Valley fruit district.

The apples bloomed very light, and any shortage of the apple crop may be attributed to this cause.

The fruit growers one and all appreciate our work. From April 10 to 16, inclusive, I did not take off my clothes. There was so much anxiety on the part

of everyone that I felt it my duty to stay up night and day and help the growers out. On the mornings of the 11th, 12th, and 13th I was very much afraid the growers would waste their fuel unnecessarily, and knowing the possible chances for much lower temperatures on the following days, namely, the 14th and 15th, I constantly urged them by telephone to refrain from firing whenever the temperature ranged no lower than  $29^{\circ}$  in the orchards. The saving of fuel proved to be the saving of the crops, because many had not laid in a supply for more than three firings. In instructing them to fire I had them light only as many fires or pots as would hold the temperature above danger. The local forecasts were very accurate both as to time and minimum temperature to be expected. I always indicated the time it would be necessary to begin firing and had the

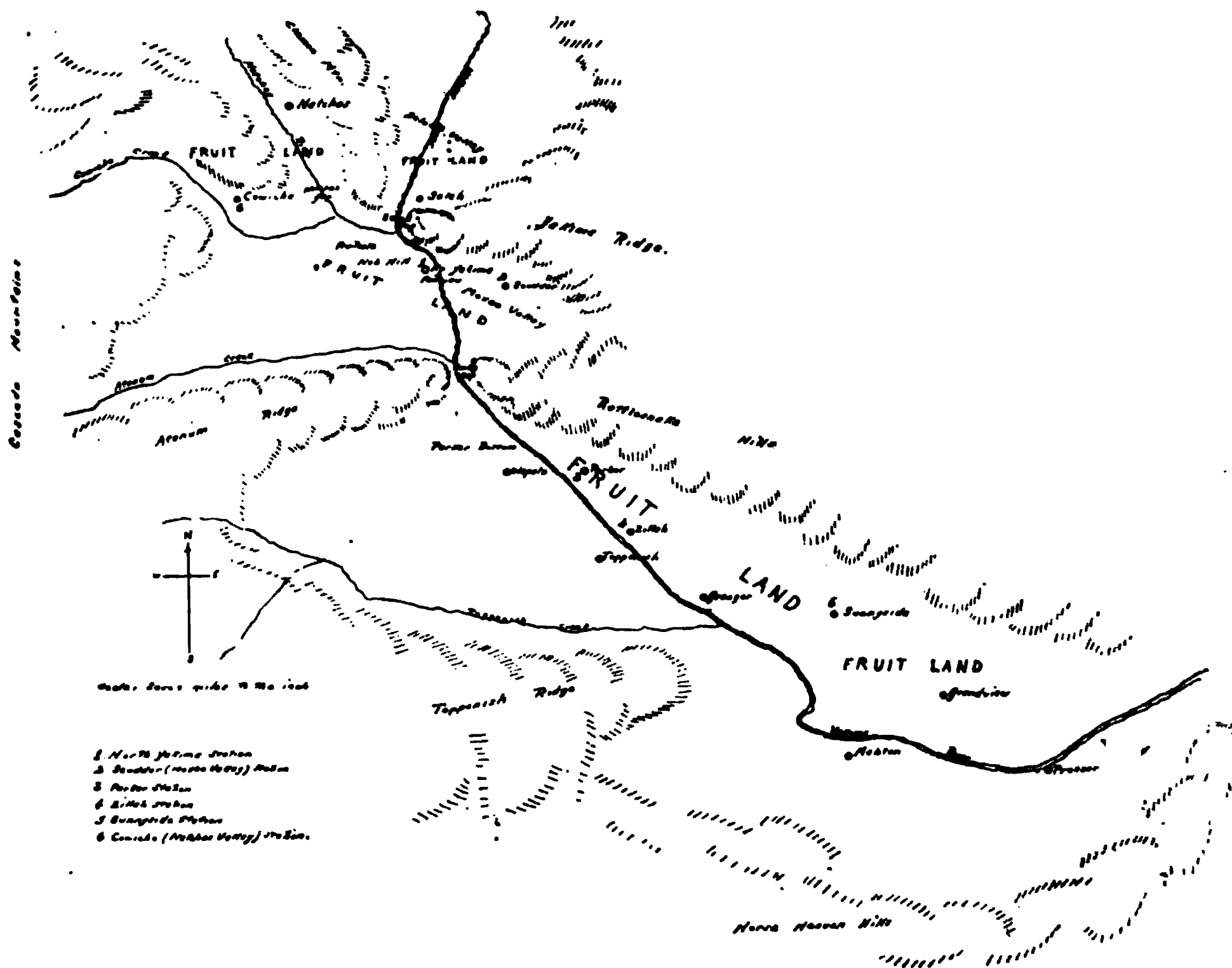


DIAGRAM B.—Yakima Valley fruit district.

growers set their alarms for that hour. In many cases I called them up during the early morning hours to warn them of their danger. We believe we have been successful, and although a few have lost some fruit, it is not because of any fault of ours. The instructions as to how to prepare were all that previous experience had taught us, and the forecasts were timely and accurate.

It is rather early to estimate what we have saved, but a half million dollars will not be far from the gross value saved this year.

*North Yakima* (by Mr. Thomas R. Reed). (See Diagram B.)—The work of protecting orchards against freezing temperatures by artificial means has been practiced for only a few years in the Yakima Valley—two I think—in the lower, and this season is the first in the upper valley. With many, therefore, it is still

in its experimental stages, while with others the work has become an established feature of annual occurrence. The number who fire their orchards has increased each year since the work began and it is safe to say that after this season's experience a vastly larger number will prepare to protect their blossoms than ever before.

The issuance of accurate predictions is a matter of vital importance to these people and the demand for the forecasts during last season has fully justified the newly inaugurated service of the Weather Bureau. The warnings have been distributed to the public from the exchanges of the Pacific Telephone & Telegraph Co. and the Yakima Valley Telephone Co. Manager Jones of the former and Manager Bartholomew of the latter have been courteous in lending us their cooperation. Warnings were issued for the following places: North Yakima, Moxee, Parker, Zillah, and Sunnyside, and were placed on the following exchanges: North Yakima, Wapato, Toppenish, Zillah, Granger, Sunnyside, Grandview, Prosser, Mabton, and Pasco. Forecasts were attempted for the first five named stations only, because observational data were procurable from these. The first two and the last, i. e., North Yakima, Moxee, and Sunnyside, are regular reporting cooperative stations of the Weather Bureau; Parker and Zillah stations were specially established for the work this spring. All stations were equipped with standard maximum and minimum thermometers; the North Yakima, Parker, and Sunnyside stations with exposed thermometers, and all except Parker with rain gauges.

Regular telephone reports of temperature and weather were received from these stations and from the Reclamation Service station at "Tieton headquarters" in the Naches Valley. The Reclamation Service officials have been particularly ready to respond to any requests made upon them for assistance, and Mr. Remington of Sunnyside and Mr. Nolan at Tieton headquarters deserve credit for the regularity with which they have forwarded messages each evening from their respective stations.

The meteorological conditions favorable for frost in the Yakima Valley include the usual conditions of high barometer following a spell of cloudy, cold weather in which the soil has lost its accumulated heat, clear sky, and very light or no wind. It is considered by local observers that frost is most likely to follow a period of bad weather and the shift of wind from the south or southwest into the northwest or north. It is popularly supposed that danger of frost is small unless the veering to northerly quarters has been preceded by quite a marked period of southerly wind. This of course may be a colloquial way of indicating the necessary intensity and duration of the cyclonic low occupying the northwest; but it is worthy of note that judging from observations this season, dangerous frost is not likely except following protracted cloudy and cold weather, and that all the really serious frosts of the season have followed days on which the maximum temperature has been under 65° and the current temperature under 60° at the time of the afternoon observation.

High barometer alone, while causing frost in other localities in the State, has repeatedly failed to bring freezing temperatures to this valley, attributable partly, perhaps, to active air movement often occurring in connection with anti-cyclonic weather. A freeze may occur here when the Northwest is occupied by low pressure; in fact, when a rain forecast would seem more legitimate than a frost warning, as on the night of the 6th of April; but this is an uncommon condition. Under such conditions the barometer may show no fluctuation worth speaking of, the surface currents may be from the south, in fact nothing to warrant a frost warning being issued except the fact of a clearing sky and a sharp fall in temperature.

The forecaster has then to determine whether the wind is to remain light and the sky clear, and this is an extremely precarious undertaking. Perhaps the diurnal rise in the barometer occurring at the time his decision is being made adds to the difficulty; and he must be able to distinguish to a certain extent between the periodic and the unperiodic movement, for it is the latter upon which he depends in a large measure to foretell the condition of the sky. Under such conditions, and unless the forecaster is sure of his position, it is wiser to place on their guard those who wish to protect their orchards, for the growers would rather be warned a few times unnecessarily than to have freezing temperatures descend on their orchards without forewarning.

The freeze occurring on the morning of April 6, when the temperature at North Yakima dropped to 25°, could scarcely be foreseen, either from the weather map or from local observations, but it is a type of local freeze which should be studied and for which the local observer should be constantly on guard. Although on this occasion the warning for North Yakima was for light frost only, no one failed to fire. Warnings for Moxee, Zillah, and Sunnyside were for freezing temperatures and firing was general throughout the lower valley. Much injury was sustained by unsmudged orchards and some orchards were injured where sufficient pots were not in use.

The ensuing freezes, which occurred with unusual frequency and severity for this section, were more easily foreseen. Between the inclusive dates of April 5 and 15 nine heavy frosts were recorded in North Yakima, and during the first half of the month there were more than this number in the neighborhood of Moxee and on the low ground below Union Gap. Seven times the minimum temperature dropped to 28° or lower at the North Yakima station. The severest freeze of the entire period occurred on the morning of the 13th of April. The North Yakima station registered 24°; in Moxee 16° was reached, and the temperature in the lower valley ranged from 17° at Sunnyside to 28° at Parker Heights. This freeze ended the firing for the season with a large number of orchardists, for attempts to cope with such conditions were futile, except on topographically favored land. On the higher lands, however, especially in the Parker Heights and Zillah districts, much fruit was saved by firing.

On the two mornings following what was very nearly a repetition of the phenomenal temperatures of the 13th was experienced. Orchardists prepared for only three nights' firing were required to procure more oil and those depending on the supply in North Yakima were unable to do so, as the amount there was insufficient. The big storage tanks in the lower valley, especially at Granger, Wapato, Outlook, and other points, enabled the growers to continue the orchard firing until the last freeze was past. It was undoubtedly a strenuous period for the fruit men and one which is not likely to be repeated for many years. It showed the necessity of using an ample number of smudge pots and also the value of orchard firing on a large scale, showing the greater ease of heating a large district than a small one, or one in which heating is practiced only in a sporadic way.

North Yakima men were unsuccessful in maintaining safe temperatures, partly because they used too few pots—generally about 40 or 50 to the acre—and partly because each heated orchard was surrounded by unheated ones, and the wind, which was a feature of several frosty nights, effected a dispersion of heat and smoke. When practically all the orchardists fire, windy conditions can much better be coped with. On the morning of the 11th in particular orchardists reported that whereas under ordinary circumstances they could raise the temperature 6° to 7° with 55 pots to the acre, on this morning



it could only be raised 3°. On the south slope of Nob Hill the smoke blew rapidly away, scarcely reaching the lower branches of the trees.

It was on this night (10th-11th) that the severest freeze occurred in the Nob Hill and Fruitvale districts, which are generally least affected by frost, the former being considered immune. The thermometer in the Weather Bureau shelter in North Yakima registered 29° and in Moxee 28°; 31° was reported from Parker, 28° from Zillah, and 33° from Sunnyside. That conditions as usually experienced suffered a complete reversal will be seen when it is stated that the temperature on Nob Hill and Fruitvale varied between 20° and 23°. The reports from these districts showed much uniformity and many readings were made from reliable instruments. Moxee—notoriously cold—varied only a degree from North Yakima, and Sunnyside, which more often corresponds with Moxee, was even warmer. An interesting problem is here presented and its solution may disclose some interesting facts. The following is suggested by observations this spring:

A study of a topographic map of the region should be made in order to appreciate the situation. The Yakima Valley is inclosed on all sides by mountain ranges varying from 2,500 to 3,000 feet in height and higher in the Cascades to the west. Access is had to the valley by two gaps on the north and one on the south. Nocturnal air drainage will always be from north to south under normal conditions, following the slope of the land, and observations show this actually to be the case. Fruitvale and the northern slope of Nob Hill are the first to benefit by the northwest breeze from the Naches Canyon, as they lie directly in its course and in close proximity to the Naches Gap, from which it issues. There may be a similar breeze from Selah Gap, a little to the eastward, but observations do not cover this point, nor are there any extensive orchards in line with Selah Gap to benefit by such a breeze if there were one.

The Naches Valley above Naches Gap forms a natural reservoir for the air drainage from a vast mountainous area, and it is natural to conclude that when the convergent air is expelled into the Yakima Valley below through the outlet formed by Naches Gap a mixing of the air and possibly an adiabatic warming ensues, which would account for the comparatively higher temperatures encountered in the region lying directly in its path, as at Fruitvale, and the comparatively lower temperatures in the Fairview and Moxee districts, which lie several miles southeast of Fruitvale.

The Weather Bureau station is located in the city of North Yakima, and, therefore, between the two districts under discussion, Fruitvale being northwest of the city and Fairview and Moxee southeast. The thermometer at this station strikes a pretty fair mean, for while Fairview is often 2° and Moxee 5° to 8° colder than the North Yakima station, Fruitvale is usually a few degrees warmer. As the breeze from Selah Gap spreads out and flows across the valley it loses its force, its temperature is lowered by radiation, and with further southeastward movement its character is changed from a protective wind to a more or less destructive one.

On the morning of the 11th, when the conditions in these districts reversed, a freezing wind was blowing from the south and southwest, having blown from this quarter throughout the night. There was no counter breeze from Naches Gap, and the minimum temperature reported from the Naches Valley above, a district from which comparatively high temperatures are usually looked for, was 22°. Thus it appears that strong connection exists between a reversal of the customary wind direction and a reversal of temperature conditions in the several localities under discussion.

I would recommend the resumption of the "key" stations at Parker, Zillah, and Sunnyside next season, and also that a station be placed in Grandview or Prosser to report daily by mail, for if forecasts are to be issued for these districts it will be necessary to have data from them.

Some of the telephone exchanges, as at Zillah and Granger, for instance, close at 9 p. m., so it is necessary to issue warnings as early as possible and avoid the necessity of modifying them at a later hour. An improvement can be effected in quicker transmission of the forecasts from Portland. It might be that by sending them by telephone they would be subject to less delay in transmission and could be placed before the public nearer 7 than 8 p. m.

In the past firing has been largely confined to the country below Union Gap, the number of pots in use being estimated at 70,000, 26,000 of this number being purchased this year. Many more orchardists in both lower and upper valleys will fire next season, and the forecaster will have greater opportunities for being of service to the individual orchardist than was possible this year. This year the field of maximum activity was rather remote and personal advice on critical nights was not feasible. However, those above the Gap kept in touch with me as long as they continued to fire and made things pretty lively. The forecasts gave general satisfaction this year in spite of its being the first year's work and performed somewhat blindly in the absence of reliable data. The work should be much easier next year and in succeeding years as local observational data accumulate and experience is acquired. A feature of the work very valuable to the fruit men is the morning forecast during protracted frost spells, for by it the grower is advised as to the need of hauling oil before nightfall.

Firing above the Gap was practiced for practically the first time this year. It resulted in a general failure to maintain a temperature of anything near 28°, and the orchardist learned the lesson that too few pots are worse than none at all, since they do not save the fruit and are a great expense.

In many orchards, on the night of the 11th-12th, the temperature had fallen to 28° by midnight, remaining below that point for seven hours; and to save the crop it would have been necessary to start a reserve number of pots before daylight to replace those that had burned out. It is difficult to estimate the loss, for the reason that the crop this year was not expected to reach that of last by any means; it being an "off year." Mr. Thompson's estimate of 1,100 cars is generally conceded to be too low. Last year about 3,000 cars were sent out from the Yakima Valley, and the general belief is that the shipment this year will be in the neighborhood of 2,000, making the total value of the crop very close to \$1,500,000. Any estimate of the loss from frost is impossible at this date, for I have seen a full crop of apples, peaches, and pears in one orchard and found the entire crop destroyed in another close by. Every orchard in the valley would have to be examined to make a correct forecast of the losses by frost.

How many took advantage of the service it is not possible to say, but the girl who handled the forecast distribution says that she was literally swamped with calls between 7 p. m. and 9 p. m. on critical nights. Since this interest was manifested by those who do not fire, it is easy to see what would be the interest taken by the increasing number who expect to engage in orchard protection in succeeding years. Beyond question it is desired to have the newly inaugurated frost service continued next season. It has required the first season to wake up the people to their part in the work, and to the value of orchard heating even in comparatively safe districts; next year will witness their greater dependency on the Weather Bureau service, and greater accuracy and assurance on the part of the forecaster assigned to this locality.

**Boise** (by Mr. Edward L. Wells). (See diagram C.)—The Boise Valley is well suited to the growing of such fruits as apples, pears, prunes, sour cherries, and common berries. Some fruit has been grown in the valley for many years, but it is only within the last few years that scientific fruit growing on a commercial scale has become an important industry.

While the entire region is more or less subject to spring frosts these frosts are rarely sufficiently severe to cause widespread damage. For this reason, prior to 1909, comparatively little attention was given to measures to protect fruit from frost injury. The spring of 1909 was one noted for a succession of damaging frosts, resulting in almost a complete failure in many orchards. This failure turned the attention of the growers toward protective measures, and some of the more progressive of them provided themselves with oil pots and

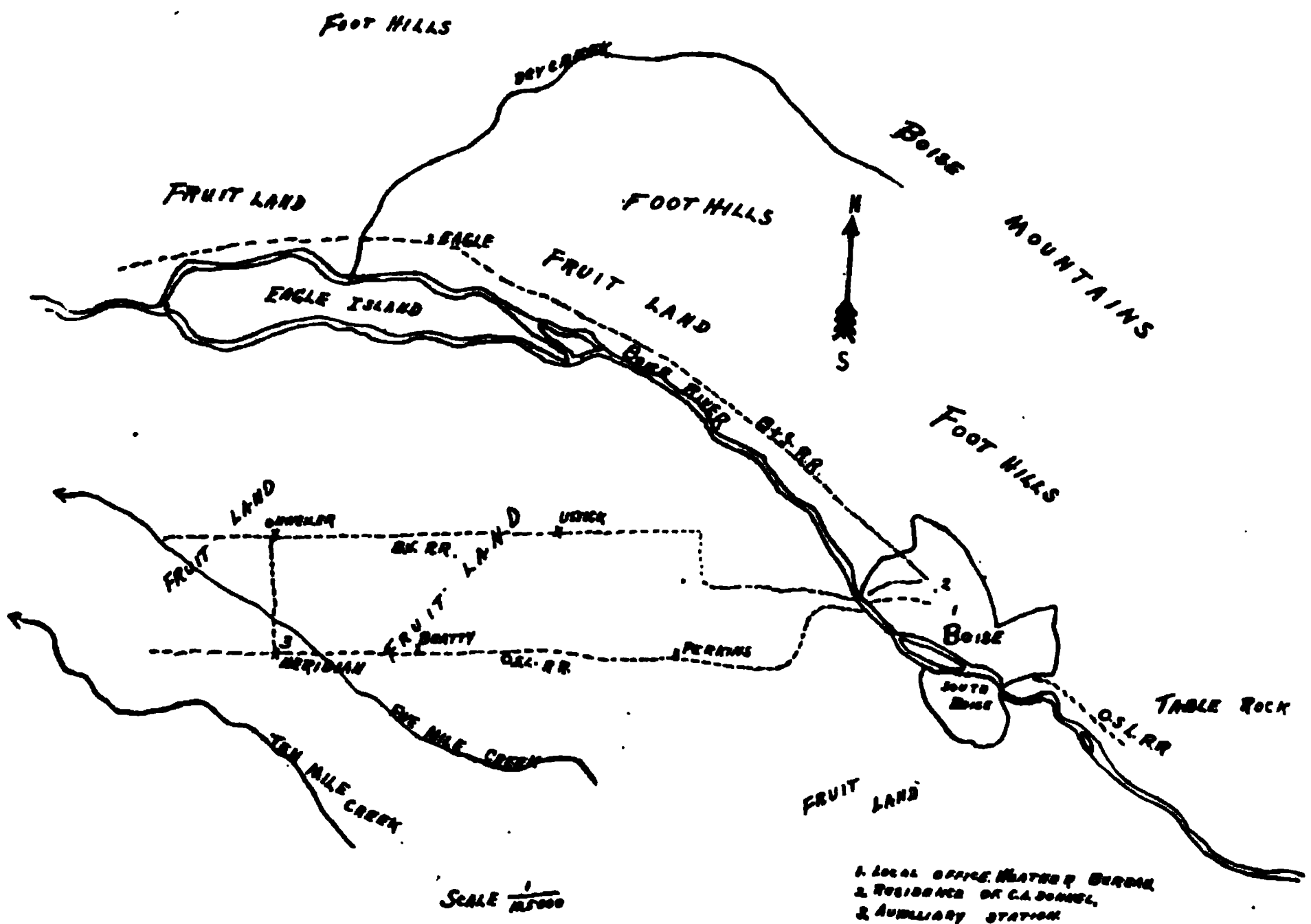


DIAGRAM C.—Boise Valley fruit district.

oil for use in 1910. The spring of 1910 was much more favorable for fruit than that of 1909, so much so that there was a good yield of fruit in most of the unprotected orchards, as well as in those that were protected. This being true, there was little increase in 1911 over the area heated in 1910; the entire area in the upper part of the valley adjacent to Boise probably not exceeding 1,000 acres. Like that of 1910, the spring of 1911 was not a good one to demonstrate the efficiency of protective measures, for while some very low temperatures were experienced, these low temperatures occurred when the buds were least susceptible to injury, and little damage occurred that could be directly traced to frosts.

It is probable that orchard heating will not become common in this valley as it is in the Grand Valley in Colorado and in the Rogue River region in Oregon, until another season like that of 1909 is experienced, when the practical value of heating can be demonstrated. It is believed, however, that the time will come when orchard heating will become general in the Boise and neighbor-

ing valleys, and the Weather Bureau should anticipate the demand for accurate information that this condition will bring about by enlarging the number of auxilliary stations and carefully studying the frost problems in every locality where fruit is grown.

The topography of this region is peculiar and gives rise to some weather conditions that make frost forecasting a difficult matter. The Boise River, in its upper reaches, flows through a rugged mountainous region. About 6 miles southeast of Boise it emerges from a deep box canyon, the mouth of which marks the head of what is known as the Boise Valley, which extends thence northwestward with increasing width toward the Snake River. Northeast of Boise are the Boise Mountains, reaching in 12 miles an elevation of 7,500 feet, or 4,800 feet above the city. Toward the southwest the ground rises in a series of widening benches. Through this bench land, where most of the large orchards are located, run several water courses, rather unimportant naturally, but forming a means for air and water drainage, and apparently playing an important part in determining local temperatures on frosty nights. The entire region may be classed as arid, having approximately 13 inches of precipitation annually at Boise, and somewhat less at points away from the mountains. Water for irrigation is supplied by the Boise River.

In fair weather there is quite a noticeable mountain and valley breeze blowing down the valley, or from the southeast from early morning to about 10 a. m., and up the valley or from the northwest in the afternoon. Frosts occur ordinarily upon the approach of a strong high-pressure area from the northwest. The outflow from this high, combined with the ascending currents already mentioned, make a strong northwesterly wind in the afternoon, which has come to be considered as the surest indication of frost. At night, in addition to the ordinary nocturnal lessening of the wind velocity, the descending current opposes the outflow from the high, causing a stagnation of the air highly favorable for the occurrence of low temperatures near the ground. At such times there is a noticeable tendency for the colder air to settle into the shallow depressions along the water courses already mentioned. When conditions for rapid radiation are particularly favorable no two thermometers in the valley will indicate the same temperature. At other times the distribution of temperature is fairly uniform. Whenever there is any considerable amount of wind at night frost does not occur.

TABLE I.—Frost observations, Boise, Idaho, 1911.

Date.	Lawn temperature, Boise, 8 p. m.	Dew point, Boise, 8 p. m.	Relative humidity, Boise, 8 p. m.	Dew point, Boise, 5.20 p. m.	Dew point, Meridian, 5.40 p. m.	Expected minimum temperature.	Minimum temperature, Boise, following.	Minimum temperature, Meridian, following.
Apr. 12.....	32	25	73	26	21	20	20	18
13.....	38	26	59	11	10	22	21	20
13.....	<sup>1</sup> 36	<sup>1</sup> 18	<sup>1</sup> 45	.....	.....	.....	.....	.....
14.....	46	16	27	10	10	26	26	26
16.....	54	28	37	22	20	32	28	30
21.....	51	33	50	28	32	.....	33	35
May 6.....	52	32	47	28	32	30	36	39
8.....	53	32	44	38	36	32	30	32
9.....	49	30	47	28	25	26	30	29
10.....	53	34	43	34	34	30	35	34
19.....	52	38	61	41	35	32	33	32
24.....	53	34	49	31	32	<sup>2</sup> 32	31	31
25.....	53	32	44	28	32	30	33	37
26.....	52	38	58	36	37	34	34	34
27.....	57	32	38	32	32	32	34	35
June 4.....	60	32	36	27	33	33	37	36
Mean.....	.....	30	.....	28	28.1	29.4	30.7	31.3

<sup>1</sup> Taken at 10 p. m.

<sup>2</sup> Not given out. No warning received.

Sometimes when the crest of the high reaches or passes this region before morning an easterly wind will spring up. A brisk easterly wind, coming as it does off the mountain range, partakes of the nature of a chinook. Usually the effect of these chinooks is hardly noticeable except over Boise and the belt of land lying between the foothills and the river. Sometimes, however, the effect becomes noticeable on the bench lands, and on rare instances the chinook has been known to pass over the city and materially affect the temperature on the bench.

It has long been known that the temperature record made from instruments exposed on the roof of the Government building, 78 feet above the ground, failed to represent conditions as experienced in the orchards. It was known first that on clear, still nights the temperature in the orchards fell to a lower point than that indicated by the roof instruments. It was known also that the dew point as found on the roof gave no index of the expected minimum temperature.

During September, 1910, a record was kept by means of instruments exposed in a cotton-region shelter mounted on the lawn in the rear of the Government building. It was found that the dew point and the following minimum temperatures at this exposure correspond very closely, the minimum being somewhat higher than the 8 p. m. dew point, except when the 8 p. m. relative humidity was above 55 per cent, in which event the minimum was somewhat below the dew point. Later the shelter and maximum and minimum thermometers were removed to the residence of Mr. C. A. Donnel, assistant observer, at 1711 Washington Street, where a record has been kept continuously since January 1, 1911. During the same period a record has been kept at Meridian, a village 10 miles west of Boise, the instruments at the two places having practically the same exposure.

It has been found that during the winter months the mean temperature at the two places is almost the same, but the range is slightly greater at Meridian. Beginning with April, however, the mean maximum and mean minimum at the two places are practically identical. The temperature goes slightly lower at Boise on cold nights and is slightly higher on warm nights.

Beginning with April 1 Meridian was supplied with an exposed thermometer, thermograph, and sling psychrometer in addition to the maximum and minimum thermometers already in use, and the dew-point observations were made daily at about 5.40 p. m., and occasionally at about 8 a. m., till June 15. At the same time dew-point observations were made daily at about 5.20 p. m., and on cold nights at about 8 p. m., on the lawn in the rear of the Government buildings at Boise. The data from both early observations were embodied in the p. m. report sent to Portland at 6 p. m.

At the beginning of the season the ordinary frost warnings from Portland were supplemented by detailed statements of expected conditions as indicated by the afternoon reports. Later this service was discontinued, presumably because of the absence of the district forecaster. These special reports were adapted to the orchard region by the official in charge at Boise and given to the telephone exchanges for distribution and to all interested persons asking for information. The office was kept open for information part or all of every cold night during the season.

For purpose of study a table has been made up (see Table I) giving for cold nights only (a) the lawn temperature at Boise at 8 p. m.; (b) the lawn dew point at Boise at 8 p. m.; (c) the lawn relative humidity at Boise at 8 p. m.; (d) the dew point at Boise at about 5.20 p. m.; (e) the dew point at Meridian at about 5.40 p. m.; (f) the expected minimum temperature as given



out to the public; (g) the following minimum temperature at the residence of Mr. C. A. Donnel, 1711 Washington Street; and (h) the following minimum temperature at Meridian.

It appears from this table, first, that the auxiliary station at Meridian is not needed for the purpose of dew-point observations, the lawn dew-point readings at Boise furnishing practically identical data; second, that the 5.20 p. m. reading, made before taking the regular observation, is too early for best results in the spring; third, that the 8 p. m. dew point on the lawn forms an excellent indication of the expected minimum temperature near the ground when taken into consideration together with the relative humidity and other local conditions. It will be seen that the minimum temperature falls below the lawn dew point when the humidity is high and is relatively higher when the humidity is low.

The experience of the season has shown that it is possible to make a very close forecast of the minimum temperature for a given place. When, however, the forecaster is confronted with the task of advising each grower what temperature to expect in his orchard, the problem becomes much more complex. For instance, on April 13, when the temperature fell to 20° at Mr. Donnel's residence at Boise and to 18° at Meridian, some standard thermometers used by the growers went as low as 12°. Again, on May 25, when the ground temperature at Boise and Meridian alike was 31°, some orchard temperatures as low as 25° were reported. Just how much of this difference is due to topography and how much to faulty exposure it is difficult to say. Some of the growers believe that the Meridian temperatures were too high, owing to the fact that the station was in town. However, as there are no large buildings in the town and no buildings of any kind near the shelter, it is evident that this is not true.

It is probable that the fact that the growers' thermometers are exposed without sufficient shelter, and are therefore subject to error from excessive radiation, may account for the discrepancy. Mr. C. A. Donnel spent the night of May 10-11 in the orchard district making comparative readings, with a view to determine how important this factor was, but the temperature was fluctuating considerably and, without assistance, it was difficult to secure accurate results, and, owing to insufficient office help, no further attention could be given this during the season. From such data as he was able to obtain it is apparent that freely exposed thermometers read from 2° to 3° below the true air temperature. This leaves some little difference to be accounted for by topography.

*Lewiston* (by Mr. W. W. Thomas). (See Diagram D.)—As has been the custom at this station in past years, the daily papers in Lewiston and the weekly in Clarkston published notices in different issues prior to the beginning of the frost season to the effect that all fruit growers should register their names and telephone numbers at the local office of the Weather Bureau. At the beginning of the season our frost-warning list, made up of the names thus registered, contained the names of all the growers in this district who desired to protect their orchards in any way against frost damage and who could be reached by telephone or otherwise.

The public was also informed through the local press that thermometers would be compared with a standard thermometer at the Weather Bureau station free of charge. A number of growers availed themselves of this opportunity, and upward of 50 thermometers were tested and the owners furnished with cards showing the error at 32°.

For the purpose of a study of the temperature conditions at different points in the valley a temperature station was established in a favorable location in the Clarkston (Wash.) section, 1½ miles southwest of the Weather Bureau sta-

tion. This station, known as "key" station A, was equipped with a standard set of maximum and minimum thermometers, an exposed thermometer, and a thermograph. It was placed in the orchard of Mr. J. H. Clear, who volunteered to take the desired observations. A similar station, known as "key" station B, was established 2 miles southeast of the Weather Bureau station, near the cen-

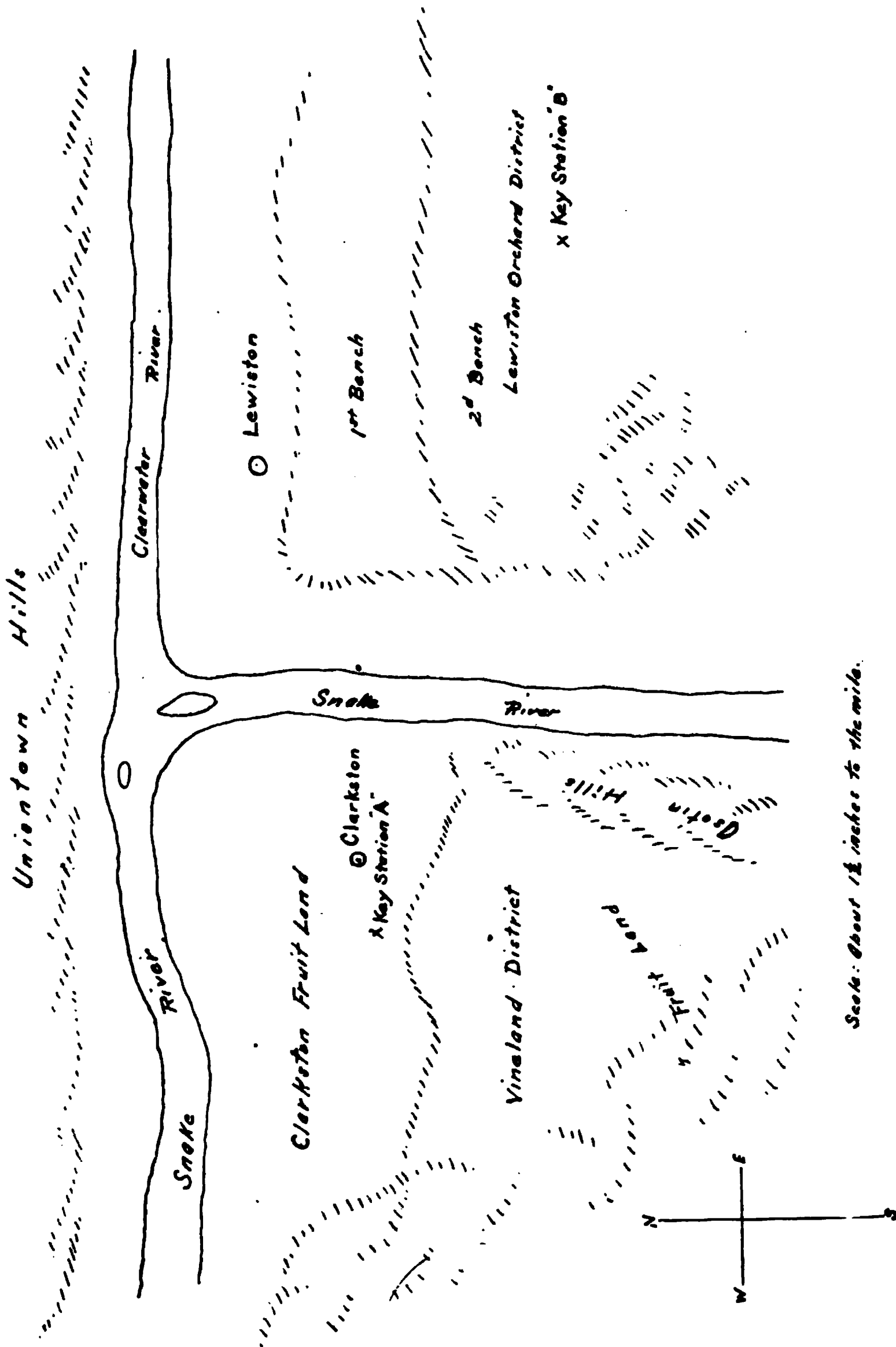


DIAGRAM D.—Lewiston-Clarkston fruit district.

ter of the present bearing orchards in the section known as Lewiston Orchards. It was placed at the home of Mr. P. W. Mullarky and was equipped with a set of Queen & Co.'s maximum and minimum thermometers and a Weather Bureau exposed thermometer. The elevation of station A is 850 feet and of station B 1,440 feet, and of the local Weather Bureau station 830 feet above sea level.



Owing to the fact that orchard heating had never been given a sufficient test in this valley to demonstrate its efficiency, the growers did not take it up to the extent that its usefulness in other fruit sections would seem to have warranted. However, a number of progressive orchardists provided themselves with fire pots and oil, either crude or slough distillate.

It is estimated that in the Clarkston section, where there are 2,000 acres in bearing trees, about 25 per cent of the orchards were provided with fire pots or heaters and about 10 per cent with smudge material, such as prunings, old straw, rubbish, etc.

Practically no frost-preventive measures were taken in the Lewiston orchards section, because in that section the trees were young and it was not desired to have them carry a full crop.

Frost warnings were issued from the office of the district forecaster at Portland, Oreg., and either accompanied the regular morning forecast or were sent out in the evening as supplemental forecasts based upon the afternoon telegraphic reports. These evening warnings usually included a forecast of the minimum temperature that might be expected the following morning, and were, for this reason, more valuable to the growers than the ordinary frost prediction that warns against light, heavy, or killing frost without indicating the probable degree of temperature that it might be necessary to combat.

The warnings received in the morning were distributed by mail and by telephone; those received in the evening by telephone only. By an arrangement with the local telephone company, the Weather Bureau was given the exclusive service of an operator at "central" during the time the warnings were being distributed. This operator kept in communication with the observer, and as soon as one grower was notified another was rung up. In this way it required but little more than an hour to distribute warnings to all growers on the frost-warning list. This method is much more satisfactory to the growers in this valley, as well as to the local station, than the one that is sometimes suggested, by which the warnings are given out by commercial clubs and by the operator at the telephone center.

The local office of the Weather Bureau did not stop at the distribution of the warnings simply. The office was kept open and available to all growers for information or advice at all hours throughout the frost period, and at critical times the observer or his assistant remained on duty all night. When the conditions threatened frost, the observer was kept informed as to the progress of the temperature, and when such action was warranted he instructed the growers to light their fires.

The fruit reached the full-bloom stage in the early days of April. During the first decade of that month there were some frost warnings issued and some frost temperatures occurred, but no heating was considered necessary, except on the morning of the 6th, when firing was general for two or three hours, ending at sunrise. The temperature on that morning fell to 30° at the Weather Bureau station and to 28° in some other places in the valley.

On April 11 adverse weather conditions set in, and on the morning of the 13th and again on the morning of the 14th the temperature was lower than ever before experienced in this valley so late in the season, the minimum at this station being 6° below freezing and in other portions of the valley from 8° to 10° below freezing. Coming, as they did, at a critical stage of the bloom, there was grave apprehension that these low temperatures had done much damage. For some time it was generally believed that all fruit was killed, except in those orchards where ample protective measures were taken. Two months after the freeze, however, the developing fruit told a different story. Conservative estimates places the peaches at about 60 per cent of a full crop

and cherries from 15 to 25 per cent, including both protected and unprotected orchards. It also shows a rather surprising situation as to the damage done, in that in a number of protected or heated orchards there will be few, if any, peaches and no cherries, while in some unprotected orchards there will be this year's average of both peaches and cherries.

The active work of the Weather Bureau during this frost campaign was eminently satisfactory and pleasing to the growers. All growers who were prepared in any way to protect their orchards were kept informed as to the current weather conditions and were amply warned of the approach of all the damaging temperatures that occurred. It is stated by competent authority that the work of the bureau in conjunction with that of the growers who heated their orchards has saved a quarter of a million dollars to the fruit industry in this valley this year.

From April 1 to May 15 observations were taken at the "key" stations and at the local Weather Bureau station at 5 p. m. daily and telegraphed to the district center at Portland, Oreg. In addition to these, special observations were taken daily at this station shortly after sunset. These consisted of the pressure, current temperature, dew point, direction and velocity of the wind, and the state of the weather. The object of these special observations was to discover, if possible, some relation between the dew point in the evening and the lowest temperature on the following morning. It was found that between these two quantities there existed no definite relation that could be relied upon to determine in the evening what the minimum temperature would be on the following morning.

The value to the fruit grower of an accurate forecast of the coming minimum temperature is obviously great, even if it is not given more than six or eight hours in advance. This fact led to a study of the radiation at this station in addition to the other observations during the frost period. It was found that in fair weather such as is favorable for frost and also for uninterrupted radiation the fall in temperature from the time of the maximum during the day to 10 p. m. was very nearly twice as much as it was from 10 p. m. to the time of the minimum on the following morning. For example, if the maximum during the day was 60° and the current temperature at 10 p. m. was 40°, the minimum on the following morning would be 30°. This relation was found to exist without material deviation at any time, particularly during the latter part of March and the early part of April, and seemed to be independent of the atmospheric pressure or of the maximum day temperature. This seems to suggest the possibility of developing a method from study of the radiation by which it will be possible to inform the growers by, say, 8 p. m. or 9 p. m. exactly what the minimum temperature will be on the following morning.

There are now between 3,000 and 4,000 acres of developed orchards in the Lewiston-Clarkston district. The planting of new orchards is going on; some hundreds of acres of orchards will come into bearing next year and the increase will continue at the rate of about 1,000 acres a year until eventually there will be something in excess of 20,000 acres in orchards in the territory contiguous to Lewiston. There will be a marked increase in the practice of orchard heating in the frost season during the next few years, and there will naturally follow a corresponding increase in the importance of the Weather Bureau to the orchardists.

It does not require a close study of the foregoing reports to become aware of the importance of frost forecasts and the complexity of the problem of making them in this part of the country. As before stated, the orchardists want to know just how cold it is going to get

in their orchard and they want this information as far ahead of the time of occurrence as possible. We know that the temperature may vary as much as  $8^{\circ}$  or  $10^{\circ}$  in orchards a few miles apart and that it is not considered necessary to protect an orchard during the blooming period unless the minimum temperature goes below  $29^{\circ}$ .

Each locality has a different environment, and owing to mountain and valley breezes needs special treatment, which is evidently beyond the capability of one man to give to all the places. The plan adopted therefore is to have the district forecast amplified by a trained scientist on the ground. This is the system in operation in handling the daily forecasts of weather and temperature at all important stations of the Weather Bureau, and it is the only way to insure good work in the making and disseminating of frost forecasts in this district.

It will be noticed from the reports of the local men that data from nine new stations, viz, five in the Yakima Valley, two in the Lewiston district, one in the Boise district, and one from Medford, Oreg., were obtained during the spring of 1911 for study purposes. At a few of these stations thermograph traces were also secured. It is now proposed to analyze these data from the forecaster's standpoint to see if it is not possible to arrive at facts which will be helpful in making frost forecasts.

In 1882 Lieut. (now Brig. Gen.) James Allen published a small memoir entitled "To Foretell Frost by the Determination of the Dew Point." It is claimed in this publication that if the dew point is above freezing in the early evening the minimum temperature the next morning will be above freezing, and vice versa if the dew point is below freezing the minimum the next morning will be below that mark. The inference to be drawn from this publication, as well as from others that preceded it, is that it is an easy matter to predict frost when the dew point is known. However, meteorologists<sup>1</sup> since then have generally reached the conclusion that the dew point of the previous evening does not give much, if any, indication regarding the minimum temperature the next morning.

Our investigations, however, rather infer that in some places the dew point is of value in this work, and Mr. O'Gara and Mr. Wells both rely on it to a certain extent in making their local forecasts of frost. Mr. O'Gara as far back as 1908 discovered a relationship between the dew point of the previous evening and the minimum temperature the next morning, and in the *Monthly Weather Review* for September, 1910, he stated:

There is a relation existing between the dew-point temperature observed in the early evening and the minimum temperature of the following morning. For the Rogue River Valley it has been found that when the atmospheric tempera-

<sup>1</sup> Moore's Descriptive Meteorology, p. 114.

ture in the early evening is between 50° and 60° F. the dew-point temperature may be relied upon generally to indicate the minimum morning temperature. It has been found that for such atmospheric temperature, with clear sky and northerly winds, the minimum temperature to be expected is 3° or 4° below the dew-point temperature as observed. If the daily temperatures have been high and the winds are from the west or westerly quarters, the minimum temperature will always be higher than the observed dew point. Again, during the latter part of the spring season with long days and a very large amount of insolation the minimum temperature usually remains the same as the dew point, or even higher, depending upon the maximum temperature during the day.

An accurate record was kept during the spring of 1911 of the dew point at Boise, North Yakima, and Medford. These dew-point observations were taken on the ground with a sling psychrometer of standard make, the first observation at about 4.30 p. m., Pacific time, and it was followed by others at irregular hours, except no second observation was taken on a few nights when the conditions were markedly unfavorable for the formation of frost. For the month of April the averages were as given in Table II.

TABLE II.—*Dew point and minimum temperature readings, month of April 1911.*

Stations.	Dew point. 4.30 p. m.	Morning minimum temper- ature.	Difference.
Medford.....	34.7	34.8	+ 0.1
North Yakima.....	22.7	36.8	+14.1
Boise.....	26.7	33.5	+ 6.8

In Table II we see the average dew point at about 4.30 p. m. and the average minimum temperature on the following morning agree very closely at Medford, while at North Yakima and Boise there are marked differences. If the differences were constant the problem of predicting exact minimum temperatures would be an easy matter, but instead there are decided variations from day to day. At Medford the range was from +12 to -8, at North Yakima from +30 to -8, and at Boise from +18 to -6. These differences were obtained from the records for the entire month, during which time all sorts of weather prevailed. If we only take dew-point observations that are followed by freezing temperatures we cut these ranges down considerably at Medford and North Yakima, but no change is effected at Boise. The reduction is from the positive side in all cases, as the negative side remains the same. The ranges with this elimination are still too great to be helpful in judging what the minimum temperature will be unless they can be still further reduced through correlations with different phases of weather, and an attempt has been made to do this with the following results:

TABLE III.—Record of observations at Medford, Oreg., from Apr. 1, 1910, to Apr. 30, 1910, inclusive.

Date.	Time of observation.	Barometer.		Psychrometer.		Dew point.	State of weather.	Wind.		Minimum temperature next morning.	Remarks.
		Actual reading.	Change last 2 hours.	Dry.	Wet.			Direction.	Force (estimated).		
1	6.45 p. m.			52.0	45.0	37	Cloudy.	nw.	Brisk.	38	Cloudy at 3 a. m. Firing general.
2	1.15 a. m.			59.0	49.0	39	Clear.	nw.	High.		
2	7 p. m.			47.0	40.0	31	Cloudy.	w.	Brisk.		Firing general on valley floor. Unsmudged orchards badly hurt.
2	10 p. m.			41.0	36.5	30	Clear.	w.	Light.	28	
3	6.30 p. m.			55.0	43.0	27	do.				
3	8.			47.0	40.0	31	do.	nw.	Slight.		
3	10.			44.0	38.0	30	do.	s.	do.		Clouded again about 3 a. m., Apr. 7.
3	10.30.			43.0	38.0	31	do.	se.	do.	27	
4	6.30.			65.0	53.0	42	do.				
4	8.15.			56.0	48.5	41	do.	s.	Slight.	39	
5	6.45.			62.0	49.5	37	Cloudy.	n.	Brisk.		Only 1° of frost. No firing.
5	11.15.			52.0	47.0	42	do.	n.	Light.	34	
6	6.30.			59.0	45.0	27	Hazy.	nw.	Brisk.		
6	7.20.			55.0	44.0	31	do.	nw.	do.		
6	9.			51.0	42.0	31	Clear.	ne.	Slight.	31	Thermometer just reached 32°. No frost.
7	6.35.			59.0	47.0	33	Partly cloudy.	nw.	Moderate.		
7	10.30.			57.5	45.0	30	do.	nw.	do.	31	
8	6.45.			59.0	48.0	36	Cloudy.	nw.	do.	32	
9	6.45.			59.0	51.0	44	do.	ne.	Slight.	44	Firing general. Some orchard temperatures raised 10°.
10	6.35.			56.0	46.5	36	Partly cloudy.	se.	Strong.		
10	9.45.			54.0	45.0	35	Clear.	se.	Brisk.	32	
11	6.45.			57.0	49.0	41	Partly cloudy.	nw.	Light.	40	
12	6.40.			59.0	50.0	41	do.	ne.	Slight.		No firing done.
12	7.45.			56.0	49.0	42	Clearing.	ne.	do.	40	
13	6.40.			52.0	42.0	29	Clear.	ne.	Brisk.		
13	11.45.			41.0	36.5	30	do.	e.	Slight.	26	
14	6.30.			64.0	48.0	29	Partly hazy.				No firing done.
14	11.30.			45.0	39.5	32	Clear.	s.	Slight.	31	
15	6.45.			70.0	52.5	34	do.	w.	do.		
15	11.			53.0	44.5	34	do.	s.	Brisk.	31	
16	6.40.			71.0	50.0	43	Hazy.			40	No firing done.
17	6.45.			76.0	57.0	41	do.			40	
18	6.45.			74.0	58.0	46	do.			38	
19	6.45.			51.0	49.0	47	Raining.	n.	Light.	42	
20	6.40.			61.0	51.0	47	Clear.			49	No firing done.
20	10.30.			49.0	46.0	43	do.	w.	Slight.	39	
21	6.45.			69.0	55.0	43	Hazy.	se.	do.	37	
22	6.50.			74.0	59.0	48	Clear.	sw.	do.	45	
23	6.45.			79.0	57.0	37	do.	s.	do.	40	

24	6.45	.....	.....	.....	80.0	60.0	45	Few clouds.....	nw.	...do....	44	Clouded about 2.30 a. m. Heavy dew Apr. 27.
25	6.30	.....	.....	.....	58.0	49.5	42	Hazy.....	nw.	High....	44	
26	6.45	.....	.....	.....	58.0	47.0	35	...do....	ne.	Strong..	.....	
26	10.15	.....	.....	.....	46.0	41.0	35	Clear.....	.....	.....	33	Clouded about 2 a. m. and began to rain.
27	6.40	.....	.....	.....	59.5	49.5	40	Raining.....	ne.	Strong..	40	
28	6.45	.....	.....	.....	60.0	46.0	29	Clear.....	n.	Light..	.....	
28	10	.....	.....	.....	45.0	40.0	34	...do....	ne.	...do....	36	
29	6.45	.....	.....	.....	48.0	47.0	46	Raining.....	w.	Slight..	45	
30	5.35	.....	.....	.....	56.0	47.5	39	Partly cloudy.....	nw.	Brisk..	.....	
30	6.30	.....	.....	.....	54.5	47.5	40	...do....	nw.	...do....	.....	
30	8.45	.....	.....	.....	50.0	46.5	43	Raining.....	ne.	Slight...	37	

TABLE IV.—Record of observations at Medford, Oreg., from Apr. 1, 1911, to Apr. 30, 1911, inclusive.

Date.	Time of observation.	Barometer.		Psychrometer.		Dew point.	State of weather.	Wind.	Minimum temperature next morning.	Remarks.
		Actual reading.	Change last 2 hours.	Dry.	Wet.			Direction.		
1	5.	28.00	-0.06	72.5	51.5	27.0	Clear.	nw.	Brisk.	Slight hoar frost on ground. Clouded between 4 a. m. and 6 a. m. Lowest temperature recorded, 36°. No firing; no damage.
1	6.30	28.00	— .06	66.0	46.0	27.0	Cloudy	nw.	Gentle.	Cleared about 8 p. m., but clouded heavily again before morning.
2	5.	27.90	— .06	63.0	50.0	36.0	Cloudy	ne.	do.	
2	6.30	28.00	— .06	57.0	45.0	30.0	do.	ne.	do.	
3	5.	28.02	— .06	53.0	44.5	32.0	do.	ne.	Brisk.	
3	6.30	28.00	— .06	52.0	44.0	34.0	do.	ne.	do.	
4	5.	28.00	— .06	41.0	39.0	37.0	Raining.	nw.	Gentle.	Rain began about 3 a. m.
4	6.30	28.00	— .06	40.5	38.0	37.0	do.	nw.	do.	
5	5.	28.00	— .06	53.0	48.0	43.0	Cloudy	nw.	do.	
5	6.30	28.00	— .06	51.0	46.0	43.0	do.	n.	do.	
6	5.	28.05	+ .06	60.0	44.0	40.0	Partly cloudy	n.	Gentle.	Slight frost. Temperature ranged from 28° to 31° over valley. Unfired tracts not injured.
6	6.30	28.15	— .06	60.0	46.0	37.0	Clear.	nw.	Very gentle.	
7	5.	28.74	— .06	67.0	53.0	40.0	do.	nw.	do.	Wind blew briskly from all quarters after 8 p. m., but principally from south and southeast.
7	6.30	28.74	— .06	60.0	46.0	40.0	do.	nw.	do.	
7	8.45	28.74	— .06	53.0	48.0	43.0	Cloudy	n.	Brisk.	At 9 p. m. sky cleared and temperature fell rapidly. Had the sky remained clear freezing temperatures would have occurred.
8	5.	28.46	— .01	58.0	46.0	38.0	do.	n.	Gentle.	Clouded in early morning.
8	6.30	28.54	+ .08	56.0	47.0	38.0	do.	sw.	Brisk.	
8	8.45	28.54	+ .06	49.0	44.0	34.0	Clearing.	sw.	Gentle.	Lowest temperature, 24°. Fired 5 below 28° occurred.
9	5.	28.09	+ .06	51.0	40.0	24.0	Partly cloudy	w.	Brisk.	Clouds prevailed till 4.30 a. m. Sky cleared and temperature went to 27° in greater part of valley. Lowest recorded, 26°.
9	6.30	28.74	+ .06	46.0	41.0	31.0	do.	w.	do.	
9	8.45	28.79	+ .05	42.0	39.0	35.0	do.	w.	do.	Wind strong from southerly and westerly quarters till 5 a. m. Changed, and sudden drop of temperature. Lowest recorded, 23°. General, 23° to 25°.
10	5.	28.79	— .05	41.0	38.0	34.0	Rain.	w.	Gentle.	
11	5.	28.54	— .05	41.0	37.0	31.0	Partly cloudy	nw.	Brisk.	
11	6.30	30.24	+ .06	34.5	39.0	28.0	do.	w.	do.	
12	5.	28.40	— .06	40.5	37.0	32.0	do.	ne.	do.	
12	6.30	28.40	— .06	37.5	36.5	32.0	Raining.	ne.	Gentle.	
12	8.45	28.45	— .05	54.0	41.5	34.0	Clear.	n.	do.	
13	5.	28.45	— .06	50.5	39.0	31.0	do.	se.	Brisk.	Wind strong from south all day. Changed to north after 8.30 p. m. Reached 32° at 2 a. m. Temperature reported, 23-25° over valley.
13	6.30	28.40	— .05	66.0	47.5	34.0	do.	se.	do.	
14	5.	28.40	— .06	61.0	46.0	22.0	do.	se.	do.	
14	6.30	28.40	— .06	30.0	34.0	28.0	do.	nw.	Gentle.	Unmuzzed tracts badly damaged.
14	Midnight	28.48	— .08	30.0	34.0	28.0	do.	nw.	do.	



15	5	28.30		70.0	52.0	33.0	do	nw.	Brisk	Remained clouded all night, with northerly winds.
15	6.30	28.30		64.0	48.0	29.0	Partly cloudy	nw.	Gentle	
15	8	28.35		55.0	46.0	36.0	do	nw.	do	41.0
16	Noon	28.35	+ .05	62.0	51.0	40.0	Clear	nw.	Brisk	
16	5	28.30		64.0	51.0	38.0	do	nw.	do	
16	6.30	28.30		63.0	47.0	35.0	do	nw.	Gentle	Temperature of 30° over valley, generally over valley. Firing not necessary.
16	10	28.32	+ .02	43.5	39.5	35.0	do	nw.	Very gentle	30.0
17	5	28.15	- .05	71.0	51.0	28.0	Partly cloudy	ne.	do	
17	6.30	28.10	- .05	62.5	49.5	35.5	Cloudy			Clouds all night.
17	9.30	28.10		58.0	47.0	35.0	do			40.0
18	5	28.40	+ .05	52.0	43.0	32.0	Partly cloudy	nw.	Brisk	Mostly clouded over key station at Medford. Temperatures of 24° to 25° recorded in north end of valley. Few fires. Upper end of valley remained clouded most of night.
18	6.30	28.45	+ .05	48.0	39.0	26.0	Clearing	n.	do	23.5
19	5	28.30	- .05	60.0	48.0	35.0	Clear	nw.	Gentle	
19	6.30	28.30		55.0	45.0	33.0	do	nw.	do	29.5
20	5	28.00	- .05	73.0	56.0	41.0	do	nw.	do	
20	6.30	28.00		67.0	53.0	40.0	do			37.5
21	5	28.14		70.0	54.5	38.0	do	ne.	Brisk	Partly cloudy during morning.
21	6.30	28.15	+ .04	64.0	52.0	41.0	do	n.	do	35.0
22	5	28.17		72.0	53.5	35.0	do	ne.	Gentle	
22	6.30	28.17		66.0	53.0	41.0	do	ne.	do	37.0
23	5	28.10		81.0	58.0	38.0	do	nw.	do	
23	6.30	28.10		73.0	56.0	41.0	do			40.5
24	5	27.95	- .05	80.0	60.0	44.0	Hazy	nw.	Brisk	
24	6.30	28.00	+ .05	71.0	52.5	33.0	Partly cloudy	nw.	do	Cloudy most of night.
25	5	27.90	- .05	64.0	53.0	44.0	Cloudy	nw.	do	
25	6.30	27.90		57.0	48.5	41.0	do	nw.	do	43.5
26	5	27.85		50.0	45.0	40.0	do	nw.	Gentle	
26	6.30	27.85		50.0	45.0	40.0	do	ne.	do	39.5
27	5	28.11	- .01	52.0	43.5	33.0	Partly cloudy	n.	Brisk	
27	6.30	28.15	+ .05	49.5	41.0	29.0	do	ne.	do	38.5
28	5	28.25		60.0	46.5	30.0	Clear	ne.	do	22° in two places for a short time. Average over valley, 26°. Firing general.
28	6.30	28.25		54.5	44.0	31.0	do	ne.	do	Clouds came about 1 a. m. Remained clouded until early morning.
29	5	28.21		68.5	51.0	32.0	do	ne.	do	
29	6.30	28.25	+ .04	64.0	49.0	32.0	do			36.0
30	5	28.05		65.0	53.0	41.0	Raining	nw.	Gentle	
30	6.30	28.05		62.0	52.0	43.0	Partly cloudy	nw.	do	44.0
										Cloudy all night with trace of rain.



15	5	28.30		70.0	52.0	33.0	do	nw.	Brisk		
15	6.30	28.30		64.0	48.0	29.0	Partly cloudy	nw.	Gentle	Remained clouded all night, with northerly winds.	
15	8	28.35		55.0	46.0	36.0	do	nw.	do		41.0
16	Noon	28.35	+ .05	62.0	51.0	40.0	Clear	nw.	Brisk		
16	5	28.30		64.0	51.0	38.0	do	nw.	do	Temperature of 30° over valley, generally over valley. Firing not necessary.	
16	6.30	28.30		68.0	47.0	35.0	do	nw.	Gentle		
16	10	28.32	+ .02	43.5	39.5	35.0	do	nw.	Very gentle		30.0
17	5	28.15	— .05	71.0	51.0	28.0	Partly cloudy	ne.	do	Clouds all night.	
17	6.30	28.10	— .05	62.5	49.5	35.5	Cloudy				
17	9.30	28.10		58.0	47.0	35.0	do				40.0
18	5	28.40	+ .05	52.0	43.0	32.0	Partly cloudy	nw.	Brisk	Mostly clouded over key station at Medford. Temperatures of 24° to 26° recorded in north end of valley. Few fires. Upper end of valley remained clouded most of night.	
18	6.30	28.45	+ .05	48.0	39.0	26.0	Clearing	n.	do		23.5
19	5	28.30	— .05	60.0	48.0	35.0	Clear	nw.	Gentle		
19	6.30	28.30		55.0	45.0	33.0	do	nw.	do	Some firing.	29.5
20	5	28.00	— .05	73.0	56.0	41.0	do	nw.	do		
20	6.30	28.00		67.0	53.0	40.0	do			Partly cloudy during morning.	37.5
21	5	28.14		70.0	54.5	38.0	do	ne.	Brisk		
21	6.30	28.15	+ .04	64.0	52.0	41.0	do	n.	do		35.0
22	5	28.17		72.0	53.5	35.0	do	ne.	Gentle		
22	6.30	28.17		66.0	53.0	41.0	do	ne.	do		37.0
23	5	28.10		81.0	58.0	38.0	do	nw.	do		
23	6.30	28.10		73.0	56.0	41.0	do				40.5
24	5	27.95	— .05	80.0	60.0	44.0	Hazy	nw.	Brisk	Cloudy most of night.	
24	6.30	28.00	+ .05	71.0	52.5	33.0	Partly cloudy	nw.	do		39.0
25	5	27.90	— .05	64.0	53.0	44.0	Cloudy	nw.	do		
25	6.30	27.90		57.0	48.5	41.0	do	nw.	do	Do.	43.5
26	5	27.85		50.0	45.0	40.0	do	nw.	Gentle		
26	6.30	27.85		50.0	45.0	40.0	do	ne.	do	Do.	39.5
27	5	28.11	— .01	52.0	43.5	33.0	Partly cloudy	n.	Brisk		
27	6.30	28.15	+ .05	49.5	41.0	29.0	do	ne.	do	Do.	38.5
28	5	28.25		60.0	46.5	30.0	Clear	ne.	do	22° in two places for a short time. Average over valley, 26°. Firing general.	
28	6.30	28.25		54.5	44.0	31.0	do	ne.	do	Clouds came about 1 a. m. Remained clouded until early morning.	27.5
29	5	28.21		68.5	51.0	32.0	do	ne.	do		
29	6.30	28.25	+ .04	64.0	49.0	32.0	do				36.0
30	5	28.05		65.0	53.0	41.0	Raining	nw.	Gentle		
30	6.30	28.05		62.0	52.0	43.0	Partly cloudy	nw.	do	Cloudy all night with trace of rain.	44.0

At Medford (see Tables III and IV) the conclusions reached after a careful analysis of the observations taken in April, 1910 and 1911, are as follows: The 5 p. m. dew-point observations show nearly as close an agreement with the minimum temperatures as do the dew-point readings obtained later in the day. The dew point more nearly agrees with the minimum temperature the next morning when the weather is cloudy at the time of the observation, and it is farthest from the minimum temperature when the weather is partly cloudy. Both the average difference and the range are least with cloudy weather and greatest with partly cloudy weather.

The winds are nearly always from the northeast or northwest on evenings with freezing temperatures, and they are usually from one or the other of these directions when no freezing temperatures occur. There is apparently just as wide a variation between the dew point and the minimum temperature when the winds are calm as there is when they are light, gentle, or brisk. On frosty nights the difference between the evening dew point and the minimum temperature the next morning is greatest when the pressure gradients are medium or steep and least when they are weak; when weak, frost seldom occurs. Frosts form oftenest when the barometer at Marshfield is about 30.3 inches (sea level) or above; on one occasion frost formed when the barometer at Marshfield the preceding evening was as low as 29.6 inches. It makes little difference regarding the height of the barometer as to the difference between the dew point and the minimum temperature, although the tendency is for a greater difference the higher the barometer reads.

The position of the highs and lows furnishes the best information in connection with the relationship of the evening dew point with the minimum temperature the next morning. When the high is in the northwest and the low in the southeast, the difference will be greatest and average  $5.6^{\circ}$  below the dew point; when the low is in the east and the high in the west, the difference will average  $-3.3^{\circ}$ ; when the low is in the northeast and the high in the southwest (moving up the coast), the difference will average  $-2.4^{\circ}$ ; when the high is inland and the low off the California coast, the difference will average  $+1^{\circ}$ , and when the high is in the north and the low in the south, the average will also be  $+1^{\circ}$ .

The application of the foregoing factors will approximate the minimum temperatures within  $1^{\circ}$  in all cases, except when the high is in the northwest and the low in the southeast, and then the approximation will be within  $2\frac{1}{2}^{\circ}$ , which is sufficiently close to be of value in determining the question of "how cold it will be." More observations will probably enable us to make other correlations that will be helpful, and it is probable that we will find some "freaks"

as our record lengthens that will need further study to properly classify.

During the two seasons there were nine cases with the dew point above 32 that were followed by freezing temperatures. In none of these cases was the minimum temperature low enough to make it necessary to start fires in the orchards, the lowest being  $29.5^{\circ}$  on April 19, 1911. The temperatures that occurred were what would be expected by using the factors for position of the highs and lows, and they were really "near cases" that are easily handled.

In 6 cases frost did not occur when the evening dew point was below 32, and these cases are puzzling. Cloudiness which prevented radiation was the cause of the absence of frost with these low dew points, but no hard and fast rule can be found to assist in predicting whether or not cloudiness will or will not prevail during the night. If the barometer is low, that alone favors cloudiness, and if high and the surrounding country is cloudy and movement sluggish, as indicated by the behavior of the barometer at stations in the vicinity, clouds will probably continue.

TABLE V.—Record of observations at North Yutima, Wash., from Apr. 1, 1911, to Apr. 30, 1911, inclusive.

Date.	Time of observation.	Barometer.		Psychrometer.		Dew point.	State of weather.	Wind.		Minimum temperature next morning.	Remarks.
		Actual reading.	Change last 3 hours.	Dry.	Wet.			Direction.	Force (estimated).		
1	4 10	28.53	+0.03	63.0	44.5	18	...	ne	10	...	Strong southwest to west wind all day.
2	6 40	28.60	+0.06	49.0	39.0	25	...	ne	8	...	Wind in puffs during evening.
3	8 50	28.67	+0.07	46.0	37.0	24	...	ne	...	...	Wind in puffs.
4	1 10	28.70	+0.03	44.8	36.3	24	...	n	...	35	Very light wind; almost none.
5	4 15	28.68	-0.02	53.7	39.0	14	10 a. st.	e	...	...	Clouds thinned out till sky was almost clear between 7.30 and 8.30 p. m. At 9 they were still quite thin.
6	6 45	28.64	-0.04	48.2	36.2	15	do.	ne	...	...	
7	9	28.65	+0.01	45.8	35.1	17	do.	ne	...	37	Cloudy all day.
8	4 20	28.54	(-)	50.0	41.0	20	do.	...	...	...	Sky was clear all night up to about 2 or 3 a. m. after that it clouded over and prevented a freeze which would otherwise have occurred.
9	8 40	28.55	(+)	44.2	38.7	31	9 a. st. few s. cu.	n	Light	...	
10	8 50	28.56	+0.01	41.8	37.3	32	Few cl. st.	n	do.	...	
11	1 10	28.56	...	38.5	35.0	30	Few a. st.	n	do.	34	
12	4 30	28.64	(-)	48.5	35.3	36	3 st. cu.	n	...	...	
13	6 50	28.63	+0.01	45.0	33.2	22	4 st. cu.	n	...	...	Wind in light puffs from north.
14	9 10	28.67	+0.04	49.0	35.2	22	...	n	Light	28	Clear all day and light southeast air.
15	4 30	28.67	(-)	52.0	38.2	15	Few cl. st.	se	...	...	Few cl. moving at tremendous speed from northwest.
16	6 50	28.66	(-)	47.4	36.0	19	Few cl.	s	do.	...	discernible from south. Haze at 9 p.
17	9 20	28.70	+0.03	44.0	33.8	17	4 cl.	s	do.	...	swiftly from northwest.
18	11	28.69	-0.01	37.5	...	...	7 cl. st.	...	...	25	northwest. Cleared off at 11.30 and
19	4 20	28.90	+0.05	57.5	43.0	23	...	n	...	...	
20	6 55	28.83	+0.04	48.8	38.2	22	...	n	...	...	Brisk north wind during day.
21	8 50	28.87	+0.04	46.2	37.2	24	...	n	...	...	Bank of st. cu. clouds low in northwest.
22	11	28.90	+0.03	43.0	...	...	...	n	...	30	Wind blew about 4 to 5 miles per hour through night, sufficiently to almost jeopardize the forecast.
23	4 20	28.80	-0.04	61.0	45.0	24	...	s	Light	...	Scarcely any motion to air.
24	7 7	28.84	-0.01	54.8	41.3	23	...	sw	...	...	
25	9 9	28.80	-0.04	46.8	36.8	22	...	...	do.	30	Calm and clear all night.
26	4 20	28.44	-0.08	69.0	49.0	25	3 cl. 2 cl. st.; 3 cu.	se	Light	...	
27	6 50	28.40	-0.04	62.7	48.0	23	10 st. cu.	w	...	45	
28	9 40	28.47	-0.07	55.0	44.5	32	2 cl. st.; 8 st. cu.	sw	...	...	Clear and calm for a large part of night. Sky became overcast by morning, preventing a freeze.
29	7	28.51	+0.03	50.0	43.0	35	4 a. cu.; 3 st. cu.	sw	...	...	
30	9 9	28.57	+0.06	46.8	40.5	33	4 st. cu.	...	...	39	Cloudy all day with trace of rain in afternoon.
31	4 20	28.60	-0.02	46.0	38.8	29	10 cu.	...	...	...	
32	6 50	28.60	+0.02	43.0	33.3	16	3 cu.	...	...	...	Southwest wind 3 to 5 miles blew all night. Some cloudiness.
33	9 10	28.65	+0.05	47.0	37.0	21	Few cu.	sw	...	29	0.01 inch of snow in afternoon.
34	11 4 20	28.73	+0.08	47.0	35.8	17	5 cu.; 5 st. cu.	sw	...	...	Northwest wind greater part of night and occasional cloudiness.
35	7	28.75	(+)	41.0	32.0	16	7 st. cu.	sw	...	26	

12	4.20	23.65	(+)	45.0	33.0	8	7 cu.	nw.	8	Cloudy all day and fresh north wind.
12	7	28.98	+ .03	40.0	30.3	10	Few cu.	nw.	5	
12	9.45	23.05	+ .05	36.7	30.2	19		nw.	6	
13	4.20	29.16	(+)	54.6	38.6	10		s.	3	Clear all day with gentle south to southeast win l.
13	7	29.20	+ .04	47.0	37.0	22		nw.	6	
14	4.20	29.25	- .02	59.0	42.4	18		se.	Light	Clear all day.
14	7	29.24	- .01	53.5	39.0	15	Few cl. st.	se.	do	
14	9.30	23.26	+ .01	42.7	33.0	16			Light	Clear nearly all day, cloudiness commencing about mid-afternoon.
15	4.20	28.95	- .08	63.0	46.2	14	Few cl.; 1 cl. st.; 3 a. st.	s.	Light	
15	7	28.90	- .04	59.0	43.3	21	10 a. st.	s.	do	
15	9.30	28.90	(+)	56.4	41.8	21	Overcast	s.	do	
16	4.20	28.95		59.0	43.3	21		nw.	10	
16	7	28.97	+ .02	49.6	39.6	23	Few cl. st.; few cu.	nw.	8	
16	9.30	23.01	+ .02	45.7	36.5	23		nw.	8	
17	4.20	28.86	- .07	60.8	44.3	22	10 a. st.	sw.	5	Sky overcast major part of day; about 25 per cent of sunshine.
17	7	28.81	- .04	56.3	42.3	23	do	s.	Light	
18	4.20	28.92	+ .05	53.0	40.5	23	Few cu.	nw.	14	
18	7	28.98	+ .06	43.3	37.0	23	Few st. cu.	nw.	10	
18	9	23.05	+ .02	42.5	36.8	28		nw.	20	Wind during night prevented freeze.
19	4.20	23.09	- .02	64.0	46.7	25	3 cl. st.	ne.	6	Shortly after 7 p. m. the wind increased to about 10 or 12 miles per hour, subsiding shortly after 8 o'clock. Increased after 9.30 p. m. and blew at intervals through night.
19	7	23.10	+ .01	54.7	43.0	28	do	nw.	6	
19	9	23.13	+ .03	50.0	40.5	28		nw.	Light	
19	10.45	23.10	- .03	48.3	39.5	28		nw.	8	
20	4.20	28.76	- .07	72.0	51.5	29		nw.	Light	
20	7	28.71	- .04	65.3	49.0	31				
21	9	28.73	+ .02	55.0	44.4	31	7 st. cu.	n.	Light	Very little motion to air.
21	4.20	28.75	+ .02	71.0	53.2	36		ne.	8	
21	7	28.82	+ .05	59.4	47.9	36		nw.	8	
21	10.45	28.88	+ .01	52.0	44.2	35		nw.	6	
22	4.20	28.93	- .01	68.0	49.7	29	Few cu.	ne.	Light	
22	7	28.95	+ .02	64.0	48.7	32	do	ne.	do	
22	9.25	28.98	+ .02	57.0	45.8	33		nw.	do	Do.
23	4.20	28.88	- .04	74.7	53.8	33		s.	6	Wind in puffs; scarcely any at times.
23	7	28.85	- .02	67.3	51.2	35				
23	9.15	28.96	+ .01	56.8	45.8	34	Few cl.; few cu.			
24	4.20	28.57	- .05	81.0	55.3	29	Few cl.; few ci. st.; few cu.	sw.	6	
24	7	28.58	+ .03	70.7	53.2	36		w.	Light	
24	9	28.60	+ .02	62.8	50.0	37		nw.	6	
25	4.20	28.65	- .03	60.0	43.8	21	4 cl. st.	nw.	10	
25	7	28.65		52.0	39.7	20	3 cl. st.	nw.	10	
25	9	28.68	+ .03	49.0	37.2	18		nw.	5	
25	11	28.67	- .01	46.1	36.2	21		nw.	Light	
26	4.20	28.44	- .04	63.8	44.3	14	3 cl. st.	se.	do	Very little motion to air.
26	7	28.44	+ .01	60.8	44.2	21	4 a. st.	nw.	do	
26	10.45	28.50	+ .06	51.8	41.0	27		nw.	do	
27	4.20	28.63	+ .04	63.0	46.8	25	Few cl.; few ci. st.	nw.	18	Wind commenced about 3 p. m. Calm at Sunnyside at 4.30 p. m.
27	7	28.71	+ .06	53.5	41.3	24	Few cl. st.	nw.	14	
27	8	28.75	+ .04	52.0	40.0	23		nw.	18	



TABLE V.—Record of observations at North Yalima, Wash., from Apr. 1, 1911, to Apr. 30, 1911, inclusive—Continued.

Date.	Time of observation.	Barometer.		Psychrometer.		Dew point.	State of weather.	Wind.		Minimum temperature next morning.	Remarks.
		Actual reading.	Change last 2 hours.	Dry.	Wet.			Direction.	Force (estimated).		
27	9.30	28.78	+ .03	50.0	49.2	24	.....	nw.	24	41	Barometer rose steadily and wind continued to blow throughout night. Wind in puffs. Wind a little steadier. Wind in gusts. Wind variable and in puffs. Day averaged about seven-tenths cloudy. Cumulous clouds commonest.  Very slight movement to air. Do.
28	4.20	28.88	.....	66.5	46.3	19	7 cu	n.	8	.....	
28	7	28.90	+ .02	60.0	44.0	22	1 cu	n.	8	.....	
28	9	28.96	+ .06	54.0	42.2	27	.....	n.	Light	.....	
28	11	28.98	+ .02	52.5	42.0	28	.....	n.	10	43	
29	4.20	28.95	.....	66.8	47.0	21	3 cu	e.	Light	.....	
29	7	28.95	.....	63.0	46.3	25	2 cu	e.	do	.....	
29	9.15	28.95	(+)	53.5	42.5	28	.....	n.	do	39	
30	4.20	28.77	— .04	70.0	48.5	21	3 cu	sw.	do	.....	
30	7	28.73	— .03	63.5	46.3	24	7 cl.; few a. st.	sw.	do	.....	
30	10	28.74	+ .01	53.3	42.0	27	.....	nw.	do	41	

Frost seldom forms at North Yakima (see Table V), as the dew-point is usually far below the freezing point. The dew-point observations taken at 7 p. m. show a closer relationship to the minimum temperature the next morning than do those taken at 4.20 p. m. For the month of April the differences averaged 14.6 at 4.20 p. m. and 12.2 at 7 p. m. For mornings followed by freezing temperatures these differences were 9 at both the 4.20 p. m. and the 7 p. m. observations. The ranges are large, being for the month from  $-8$  to  $+30$  at 4.20 p. m., and from  $+3$  to  $+23$  at 7 p. m. On mornings followed by freezing temperatures they were from  $-8$  to  $+16$  at 4.20 p. m. and from  $+3$  to  $+14$  at 7 p. m. There is a strong probability that the dew-point observation taken at 4.20 p. m. on the 4th is in error, as it is the only date during the series when the following temperature sank below the dew-point, and the observation taken at 7 p. m. on that date gave a dew-point 13 points lower, thus making the minimum temperature  $5^{\circ}$  higher instead of  $8^{\circ}$  lower, as computed from the 4.20 p. m. observational data. If we exclude this apparently erroneous reading, we get a range on frosty mornings from the 4.20 p. m. observation from 0 to  $+16$ , which, as will be seen, is  $5^{\circ}$  greater than that obtained from the observations taken at 7 p. m.

It seems to make no difference at North Yakima whether the weather is clear or cloudy when the dew-point observation is taken as to the variations in the range between that point and the minimum temperature the next morning. When clear the average difference for 18 observations was 13.3, and when cloudy for 7 observations it was 12.6. On partly cloudy evenings the average was 19. There were five mornings with freezing temperatures when the winds during the preceding evening were from the southeast or south and four when they were from the north or northwest. There were many other evenings with the same directions that were not followed by freezing temperatures.

The differences between the evening dew point and the following minimum temperature were practically the same, no matter what direction the wind blew from or whether or not the pressure gradients were for light or strong winds. No freezing temperatures followed those evenings when the winds were brisk, but when they were light there were four and when moderate there were five mornings with freezing temperature. The dew point at North Yakima averaged 22.7 at 4.20 p. m. and 24.6 at 7 p. m., but when above 32 at either of these hours no frost need be expected, which is contrary to the conditions in the Rogue River Valley, where there were nine days in two years with the dew-point above 32 that were followed by freezing temperatures. Freezing temperatures occur at all heights of the barometer, beginning with readings as low as 29.80 inches up to 30.50

inches or more. Owing to the uncertainty in the temperature factor used in reducing barometer readings to sea level at the altitude of North Yakima the isobars sometimes appear to be misplaced, and very little weight can be given to the fact of their being crowded together or wide apart when making frost forecasts for this station.

When the high is in the southwest (moving up the coast) and the low in the northeast, the dew-point will be from 0 to 9° lower than the minimum temperature the next morning; when the high is in the west and the low in the east, the dew point will be from 7° to 16° lower; when the high is in the northwest and the low in the southeast, these differences will range from 10° to 15°; and when the high is in the east and the low in the west the difference was 15° on the only occasion when this situation occurred.

The lowest dew-point at 4.20 p. m. that was followed by freezing temperature was 8, and the lowest at 7 p. m. was 10, while the highest (excluding the apparently erroneous observation on the 4th) were 29 and 23, respectively. These factors show variations too large to be of much value in placing the minimum temperatures at North Yakima, but they are helpful when taken in consideration with other conditions, and it is believed the dew-point observations should be continued at this station as well as at Medford. It is worthy of note that when the gradients were steep at North Yakima and freezing temperatures occurred, the high was in the southwest and the low in the northeast, and radiation played but a small part in cooling the air, but instead genuine freezes occurred with a great deal of cloudiness.

TABLE VI.—Record of observations at Boise, Idaho, from Apr. 1, 1911, to Apr. 30, 1911, inclusive.

Date.	Time of observation.	Barometer.		Psychrometer.		Dew point.	State of weather.	Wind.		Minimum temperature next morning.	Remarks.
		Actual reading.	Change last 2 hours.	Dry.	Wet.			Direction.	Force (estimated).		
1	5.15	26.98	-.05	60.8	46.9	18	Clear	n.	10	35	Sky clouded during night.
2	5.15	26.88	-.05	58.6	41.0	15	Cloudy	w.	4	35	Partly cloudy to cloudy during night.
3	5.20	26.86	-.04	57.7	41.4	19	do.	w.	2	35	Do.
4	5.20	26.84	-.03	56.8	42.1	25	do.	nw.	5	35	Do.
5	5.20	26.97	-.01	42.4	39.4	36	Light rain.	ne.	3	33	Cloudy all night.
6	5.20	26.90	-.02	48.2	36.5	19	Clear	nw.	14	28	Clear all night.
7	5.20	27.25	-.02	53.2	42.3	29	do.	nw.	4	28	Do.
8	5.20	27.25	-.01	56.7	40.6	18	do.	sw.	4	28	Chinook began during night.
9	5.20	27.25	-.02	61.2	47.8	34	Light rain.	e.	2	33	Do.
10	5.20	26.98	-.02	54.0	43.5	32	do.	se.	8	47	
11	5.20	26.95	-.01	51.8	40.8	28	Cloudy	w.	8	35	
12	5.20	27.10	-.03	51.8	40.8	28	Light snow	w.	10	34	
13	5.20	27.10	-.03	54.5	42.6	28	Light snow	w.	10	24	
14	5.20	27.09	-.04	53.1	40.9	28	Cloudy	se.	4	24	partly cloudy midnight to 2.20 a. m.
15	5.25	27.23	+.04	58.3	45.0	26	do.	n.	12	24	
16	5.25	27.26	+.02	58.0	45.3	25	do.	n.	2	20	Generally cloudy all night, 12th-13th.
17	5.20	27.45	+.03	64.1	52.4	11	Clear	n.	6	20	Clear all night.
18	5.20	27.47	+.02	63.1	50.9	18	do.	n.	2	21	Do.
19	5.20	27.52	+.02	63.5	50.1	16	do.	n.	3	21	Do.
20	5.20	27.60	+.02	60.4	46.0	10	do.	n.	4	26	Do.
21	5.20	27.43	-.07	60.4	41.6	13	do.	se.	9	31	Do.
22	5.20	27.13	-.05	63.3	45.0	22	do.	nw.	4	28	Do.
23	5.20	27.13	-.04	59.2	42.3	20	do.	n.	9	28	Chinook conditions to night.
24	5.20	27.19	-.02	51.3	38.8	22	do.	w.	9	38	Chinook conditions to night.
25	5.20	27.15	-.16	45.4	34.7	30	Light snow	n.	14	32	Snow and rain during night.
26	5.20	27.26	+.05	51.4	41.7	34	Cloudy	n.	6	37	Cloudy all night.
27	5.20	27.24	-.02	45.3	40.6	35	Partly cloudy	se.	3	30	Clear part of night.
28	5.20	27.23	-.02	55.9	43.2	28	do.	se.	3	33	Clear all night.
29	5.20	27.23	-.01	50.7	42.3	33	do.	se.	2	33	Do.
30	5.20	27.21	-.02	66.4	49.6	33	Clear	nw.	8	37	Do.
31	5.20	27.23	+.02	57.6	47.7	38	do.	n.	3	40	Chinook conditions during night.
32	5.20	27.24	+.04	71.6	51.1	31	do.	se.	7	49	Generally cloudy all night.
33	5.20	27.06	-.04	71.6	54.3	40	Partly cloudy	n.	4	45	Cloudy and rainy all night.
34	5.20	26.97	-.02	65.1	50.0	36	Cloudy	n.	6	41	Cloudy and damp all night.
35	5.20	26.97	-.02	47.3	42.8	36	do.	n.	6	42	Cloudy all night.
36	5.20	27.16	+.01	50.4	45.9	41	do.	n.	7	38	Partly cloudy to clear during night.
37	5.20	27.22	+.01	59.4	47.5	36	do.	n.	10	35	Chinook conditions at night.
38	5.20	27.22	+.01	61.3	44.6	37	Partly cloudy	se.	3	44	
39	5.20	27.12	-.08	61.3	45.3	27	do.	n.	4		
40	5.20	27.13	-.01	64.1	44.6	34	Clear	sw.	2		

On account of elevation the danger of frost in the Boise district (see Table VI) extends over a longer period than at either of the other places which have been considered. During the spring of 1911 there were 10 mornings in April with the temperature  $32^{\circ}$  or lower and 3 in May. The May frosts were not heavy, and that our comparison may cover the same period in all three districts only those for April have been considered in this discussion.

Regular dew-point observations were taken at 4.20 p. m., Pacific time, and quite a number were taken at about 7 p. m., but there were not enough of the latter to definitely determine its advantages as compared with the earlier observation. Mr. Wells, the official in charge of the Boise station, states in his report that "the 8 p. m. (7 p. m. Pacific time) dew-point on the lawn forms an excellent indication of the expected minimum temperature near the ground when taken into consideration together with the relative humidity and other local conditions"; also, "that the 5.20 p. m. (4.20 p. m. Pacific time) reading made before taking the regular observation is too early for best results in the spring." Mr. Wells thinks when the humidity is high the minimum temperature is usually below and when the humidity is low it is above the dew-point of the previous evening. The same rule works with the dew-point; when it is high the minimum temperature is below and when low it is above, and the lower the dew-point the higher above the minimum temperature will be, therefore there is no special object in bringing the humidity into the question when the dew-point answers the same purpose.

The average dew-point at Boise at 4.20 p. m. for the month of April, 1911, was 26.7 and the average minimum temperature the next morning was  $33.5^{\circ}$ , which is  $6.8^{\circ}$  higher. As some of the differences were minus, the average of the difference column is greater than 6.8, being, in fact, 8.5; and the range is very great, being from +18 to -6. This shows very plainly that the evening dew-point is of no value in placing the minimum temperature the following morning, unless we can segregate the observations in such a way as to get uniform differences under similar conditions.

When the weather is clear the differences between the 4.20 p. m. dew-point and the following minimum temperature averaged 11.2, and they ranged from +18 to -1; when partly cloudy the average was 8 and the range was from +17 to -5; and when cloudy the average was 6.9 and the range from +18 to -6. Thus we see the average is greatest and the range is least with clear weather and the average is least and the range greatest with cloudy weather. It is not the average but the range that prevents the use of the dew-point in this connection.

As the time of the observation was nearly at the time of the most rapid diurnal fall in pressure, the two-hour pressure changes were

nearly always minus. On the few occasions when they were plus the average difference was 5.4 and the range from +10 to -6. On only one occasion was the weather clear, with a two-hour plus change in pressure, and then the minimum the next morning was 10° higher than the dew-point the previous evening. If we exclude this instance, the range will be from -6 to +3, and, as a rule, we should look for a minimum temperature about 3° or 4° lower than the dew-point the previous evening.

During the 10 mornings when the minimum temperature was 32° or lower, 6 were during clear weather, 1 with partly cloudy weather, and 3 with cloudy weather. On the clear nights the difference ranged from +18 to -1, on the partly cloudy night the difference was -5, and on the 3 cloudy nights the range was from -2 to -6. There were 8 mornings when the minimum temperature was lower than the previous dew-point, and on 5 of them freezing temperatures occurred, and on 3 mornings the temperature was above 32°, the warmest being 36°.

The highest current temperature followed by frost was 63°, the night being clear and very favorable for radiation. Two freezing temperatures occurred when the winds were light, four with winds from 5 to 10 miles an hour, and three with winds over 10 miles an hour, which shows there is apparently no connection between dew-points, freezing temperatures, and wind velocities, as the variations were as marked with light winds as with those that were stronger. Freezing temperatures occurred twice with north winds, four times with northwest winds, twice with southeast winds, and once with a south wind, and the variations were as marked with one direction as with another. If we consider the bearing the height of the barometer has on the agreement between the evening dew-point and the following minimum temperature, nothing conclusive is to be obtained. Freezing temperatures occurred once with a barometer as low as 29.80 inches, once 29.90 inches, three times 30 inches, twice 30.20 inches, once 30.30 inches, once 30.40 inches, and once 30.50 inches.

Regarding the position of the highs and lows, there were six cases with the high in the northwest and the low in the southeast, and the differences between the dew point and the following minimum temperature ranged from +10 to -4, with an average difference of +2.6. There was only one case for the other positions of the highs and lows, and no conclusions can be drawn from them. The principal freezing temperatures of the month occurred during the passage of a slow-moving high-pressure area from the north California coast to Cape Flattery and thence southeastward to the Great Salt Lake Basin. During the first two days the weather was cloudy and windy; then it became clear, and radiation was excellent.

From the foregoing analysis of the relationship between the evening dew point and the following minimum temperature we arrive at the following conclusions:

First. Dew-point observations taken from two to four hours later than the time of taking the regular evening observation agree more closely with the following minimum temperature than do those taken at the regular hour.

Second. The average difference and the range of the differences between the dew point and the following minimum temperature are greatest with clear or partly cloudy weather and least with cloudy weather.

Third. No inferences can be drawn from wind direction, wind velocity, steepness of barometric gradients, relative height of the barometer, and two-hour pressure changes as to the difference between the evening dew-point and the following minimum temperature.

Fourth. The position of the highs and lows gives important information at Medford regarding the differences between the evening dew-point and the following minimum temperature, and knowledge of this character is of some value at North Yakima, but of little use for the Boise district.

The investigation of the relationship of the evening dew point with the following minimum temperature, besides bringing out the preceding conclusions, also developed the fact that at North Yakima no freezing temperatures occurred when the wind backed a point or two after the 4.20 p. m. observation. Three freezing temperatures occurred when the wind veered a point, five when it remained steady, and one when it shifted from the south to the northwest. Also no damaging temperatures occurred at any place when the preceding maximum temperature was above 68°. At North Yakima the highest maximum temperature followed by a freezing temperature was 64°, and the highest current temperature was 61°; at Boise the highest maximum was 65° and the highest current was 63°; at Medford the highest maximum and the highest current were both 68°; and at Lewiston the highest maximum was 68° and the highest current 52°.

Mr. Thomas states in his report that "it was found that in fair weather, such as is favorable for frost, and also for uninterrupted radiation, the fall in temperature from the time of the maximum during the day to 10 p. m. was very nearly twice as much as it was from 10 p. m. to the time of the minimum the next morning."

To follow up this clue six nights at Medford, four at North Yakima, five at Lewiston, five at Clarkson, and four at Meridian have been selected as those best representing the conditions specified, viz, clear nights with good radiation weather. followed by minimum



temperatures of  $32^{\circ}$  or lower, and computations have been made to ascertain what the minimum temperature would be the next morning.

The average difference between the computed minimum temperature and the actual minimum temperature on these nights was  $3.7^{\circ}$ , and the absolute range was from  $12^{\circ}$  too high to  $6^{\circ}$  too low. There were 5 cases when the computed minimum temperature exactly agreed with the actual minimum temperature, and out of the total number of 24 cases there were 14, or a little over half, that did not vary more than  $3^{\circ}$ . This information, therefore, is of value to the local forecaster, but too much dependence should not be placed upon it, as the liability of error is great and the chances are that the estimated minimum temperature will be placed too high, which is a grievous fault.

At Lewiston and Clarkston there were three cases when the computed minimum temperature agreed with the actual minimum temperature, while in all the other cases the computed minimum temperature was too high. At Medford, on the other hand, there was one agreement and three cases when the computed minimum temperature was too low and only two cases when it was too high. It is possible that some of the dates selected did not entirely fulfill the conditions, but conditions are seldom perfect and frost must be predicted, when seemingly the winds are too strong and when there is more or less cloudiness to check radiation.

Another rule that can be followed by the local forecaster is to ascertain the median point between the maximum and minimum temperatures, find the average time it occurs, then take an observation of the temperature at that time, subtract the reading obtained from the maximum temperature, and the remainder will be the approximate fall that will occur to reach the minimum.

Computations after this plan have been made for the same dates as those used in testing the plan offered by Mr. Thomas. On account of the time error not having been noted on the thermograph sheets from some of the stations the exact median point can not be definitely located, but it is not far from 8.30 p. m. By considering 8.30 p. m. the halfway point between the maximum and the minimum temperature, we can arrive at a closer approximation to the minimum temperature than we can by waiting until 10 p. m. and considering that the temperature has fallen two-thirds of the range between the maximum and minimum temperatures. This method of arriving at an approximation offers the further advantage of giving the forecaster earlier information, which of itself is greatly to be desired.

The average differences under this plan are  $2.9^{\circ}$  as compared with  $3.7^{\circ}$  by the plan of Mr. Thomas. The variations are from  $+6$  to  $-8$ , and there are 3 agreements and 16 cases where the computed mini-

imum temperature was too low and only 7 where it was too high. This is also an advantage, as it is better to make a mistake on the safe side than to predict that it will be warmer than what actually happens. At North Yakima and Meridian the agreements were remarkably close, and in no instance was the difference greater than  $4^{\circ}$ . At Lewiston, Medford, and Clarkston the agreements were not so close, but they were closer than were the computations based on the 10 p. m. formula.

Mr. Wells reports that a rather unsatisfactory investigation, made by Mr. C. A. Donnel, leads to the belief that "freely exposed thermometers read from  $2^{\circ}$  to  $3^{\circ}$  below the true air temperature." Professor Cox arrived at the same conclusion in his investigations in the cranberry marshes at Mather, Wis. He states:<sup>1</sup> The mean depression of the outside thermometers below those in the shelters at the six stations on the bog for the entire season of 1907 was  $3^{\circ}$ ." Investigations made by Prof. Willis I. Milham at Williamstown, Mass., on 36 cold and cloudless nights showed the temperature averaged  $3.9^{\circ}$  lower in the open than in a shelter. It is probable that on frosty nights the difference between the true air temperature and the temperature indicated by thermometers hung on trees in orchards is not less than  $3^{\circ}$  and may average as much as  $4^{\circ}$ , with variations as great as  $6^{\circ}$  or  $7^{\circ}$ , depending upon the radiating qualities of the air, the density of vegetation, and the character of the soil.

The thermometers hung on trees, while not indicating the true air temperature, indicate, roughly, the temperature of the trees themselves, which is the temperature the orchardist is interested in, but it is not the temperature the forecaster can predict, because it varies so greatly in different orchards, and even in different parts of the same orchard.

The accepted standard for true air temperature is obtained by exposing a thermometer in a louvered shelter in an open place where the air can move freely through it. The shelter will keep the instruments dry and screen off the direct and reflected sunshine, which otherwise would affect the reading of the instruments. Instruments so exposed will read nearly alike if they are elevated a few feet above the ground and the territory covered is not too large and has the same physical characteristics. These are the temperatures that to a certain extent control the variations due to radiation from the vegetation and soil, and they are the temperatures that the forecaster endeavors to predict. The variations should be ascertained by the individual orchardist for himself. This can approximately be done by comparing the readings made in the orchard with those made in the louvered shelter.

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<sup>1</sup> See p. 27, Weather Bureau Bulletin T.

Professor Cox<sup>1</sup> found that the temperature on cold nights varied a few rods apart as much as 6° or 8° in the cranberry marshes at Mather, Wis. It is probable we would not get quite so great differences in the orchards as he did in the cranberry marshes, but it would be considerable, and under similar conditions the same or very nearly the same every night. When an orchardist knows how the temperatures vary in his orchard and how these temperatures compare with those obtained in a louvered shelter in the neighborhood, it is an easy matter for him, with the help of the forecasts, to calculate just how cold it will be at his place whenever frost is predicted.

The responsibility for accurate forecasts should rest on the district forecaster for the prime "key" stations, upon the local forecaster for the secondary "key" stations and for the individual orchards as far as practicable, and upon the orchardist for his own immediate locality when the local forecaster can not handle that particular section for him.

The main reliance of the district forecaster is on his weather charts, which should be classified into types and studied from that point of view. Even with their help it is not always possible to prevent errors, as we all know how business men sometimes make mistakes in their accounts, which are based upon certainties, and we should not expect perfection in work that to some extent is based on uncertainties.

We have in this district damaging temperatures, effects of which can be classified under three heads: First, the common hoar frost, which occurs when the temperature sinks to the dew-point and the dew-point is below freezing; second, a dry freeze, when the temperature sinks below the freezing point and the dew-point is still lower than that mark; and, third, general freezes, when the air is thoroughly mixed and the whole mass is below freezing. The first two are usually the most damaging, but whether the dry freeze or the frost is the worst the writer does not know. Professor Brown, of the Corvallis Agricultural College, believes the most damage is done by the dry freeze, and he is probably correct in his surmise, as the thawing of a plant incased in ice would be slower than the thawing of one that was frozen without such a covering. It is a well-known fact that the slower the frozen plant thaws the less will be the damage done. In the case of the general freeze the weather is usually cloudy or partly cloudy and the winds are always somewhat brisk, if not actually strong. The thawing in such cases is always slow, and these freezes are the ones when the statement is so often made that "The damage was not so great as expected." The first two, occurring when there is but little or no wind, are due largely to radiation, and in the

<sup>1</sup> See Weather Bulletin T, p. 47.

last, provided it occurs when there is considerable wind, radiation plays but a small, if any, part in the process.

At North Yakima nearly all the damaging temperatures are with dry freezes, and hoar frost is seldom seen. At Boise and Lewiston frost sometimes forms, but sometimes the dew-point is too low and a dry freeze occurs. At Medford frost forms most frequently and dry freezes are rare. At all four places the general freeze occurs, and these are the most difficult to forecast on account of the dynamic heating that takes place in some of the valleys, which upsets the calculations. This is notably the case in the Boise district and to a less extent in the Yakima Valley. The general freeze occurs with a relatively low barometer and the other two classifications with a relatively high barometer and with clear or partly cloudy skies and quiet air.

The five accompanying weather charts represent typical frost conditions, beginning with the general freeze where the whole mass of air reached a low temperature with general cloudiness and brisk southwesterly winds. As the high moved up the coast the clouds dissipated and the winds diminished in force until the air became comparatively still and radiation from the sun to the ground in the daytime and from the earth into space at night was uninterrupted. The coldest weather came during the first three days. After the high has reached its farthest point north and begins to move southeastward, the warming done in the daytime is so great that the loss at night is insufficient to cause very low temperatures.

It is not uncommon for high-pressure areas to make their appearance off the California coast, as in the case typified on Chart I, and then disappear without moving north, probably being influenced by low-pressure areas in the bight of the Pacific Ocean surrounded by the islands and coast line of southern Alaska. It is necessary for the forecaster to determine as early as possible whether or not the high-pressure area will have sufficient strength and character to assert its supremacy, and in doing this his largest asset is good judgment based upon past experiences.

Chart VI shows composite curves of the behavior of the thermometer between the time of the maximum temperature and the following minimum temperature. These traces cover only days with uninterrupted radiation, and they are interesting in showing that at North Yakima and Lewiston there are warm currents at night which interrupt the regularity of the curve, and they must be considered in making the forecasts of the degree of cold expected. Also at Medford the curve is sharpest and the Clarkston and Meridian curves are the most rounded at the time of lowest temperature. The rise from the lowest point is rapid and at all five stations the temperature is above

the freezing point by 7 a. m., except at Meridian, where the thawing weather does not set in until a half hour later.

From both the meteorological and pathological side of the problem it would seem that the best protective measures would be a combination heating device that would heat the orchards between 3 a. m. to sunrise and then throw out a dense smudge to screen the fruit from direct sunlight for three or four hours. Of course, during general freezes neither direct heating nor smudging will avail, but for dry freezes and frosts, especially the former, a smudge seems almost a necessity during the first few hours after sunrise on account of the rapid rise in temperature which the curves show at all of the places investigated.

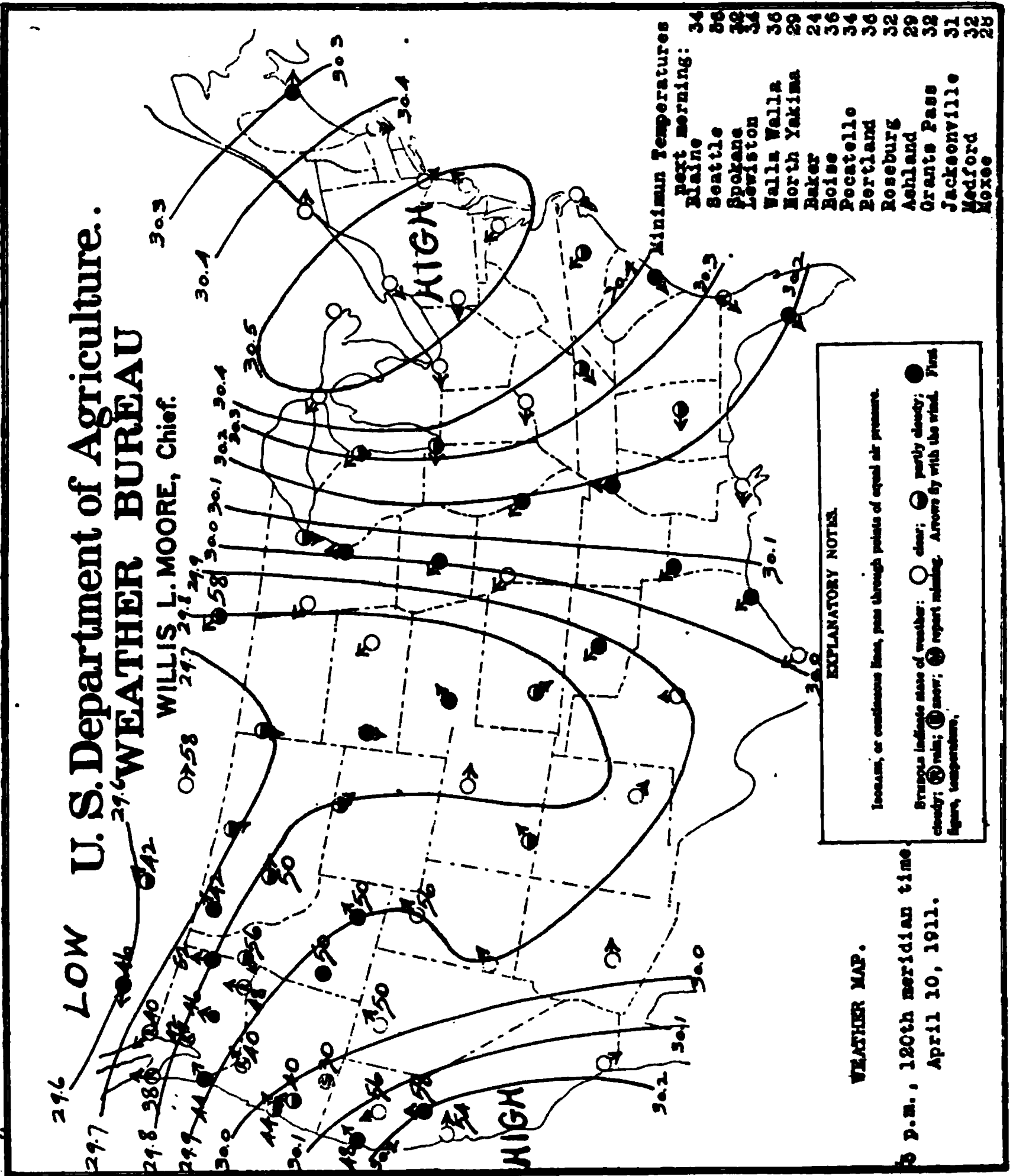


CHART I.

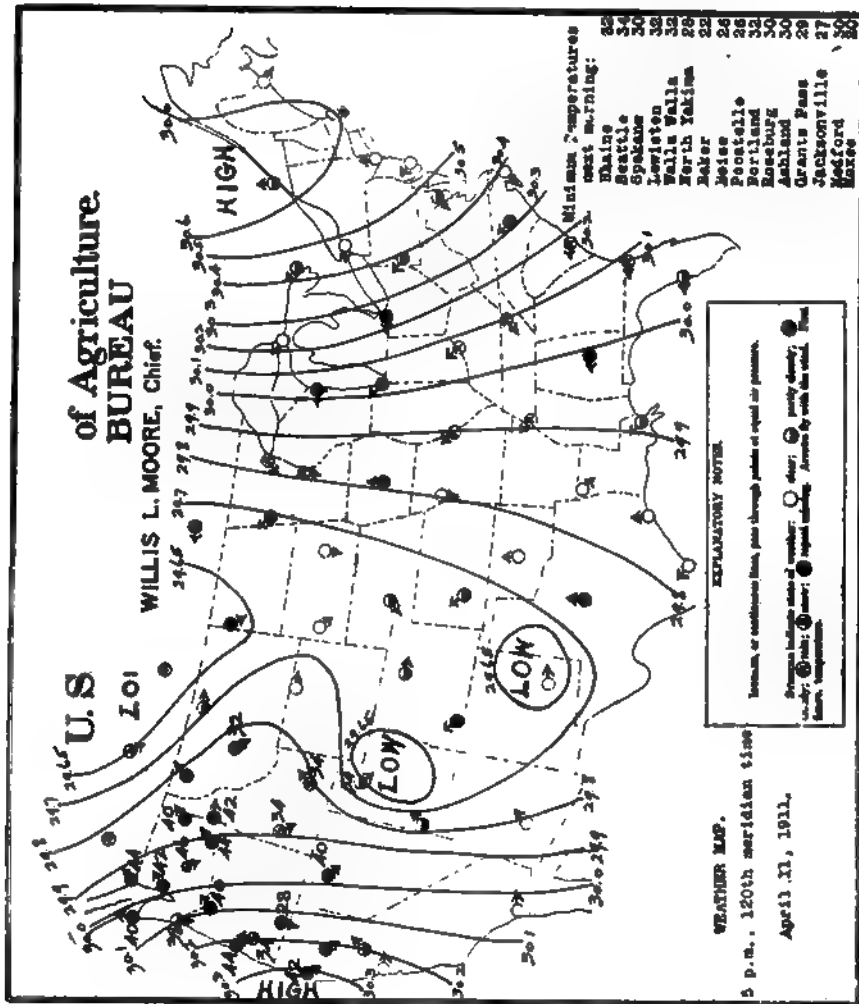
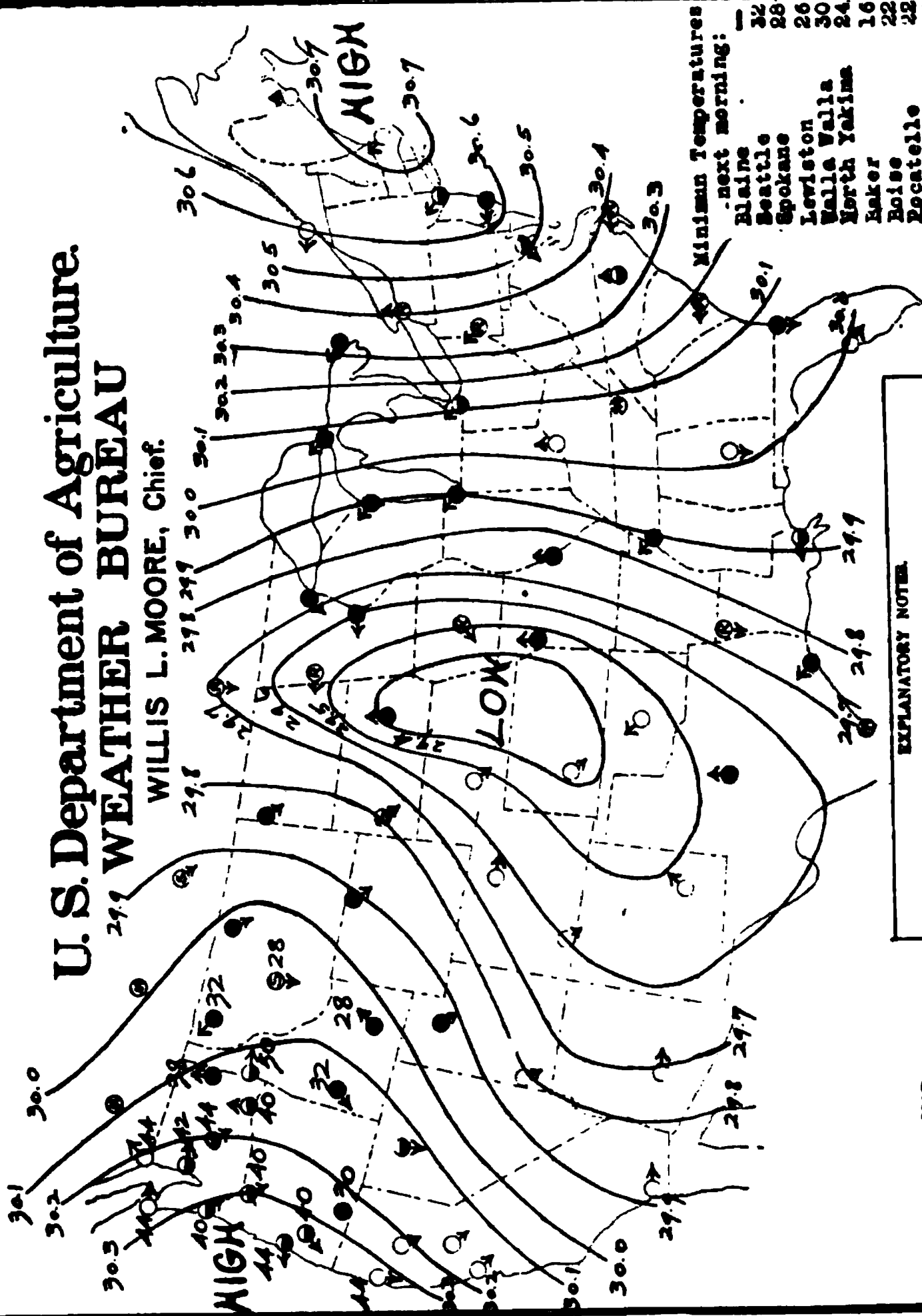


CHART II.



# U. S. Department of Agriculture. WEATHER BUREAU

WILLIS L. MOORE, Chief.



**EXPLANATORY NOTES.**

Isobars, or continuous lines, pass through points of equal air pressure.

Shadows indicate state of weather: ○ clear; ⊙ partly cloudy; ⊕ cloudy; ⊖ rain; ⊗ snow; ⊕ report missing. Arrows by the wind. Plus signs, temperature.

WEATHER MAP.

8 p.m., 120th meridian time.

April 12, 1911.

CHART III.

U. S. Department of Agriculture.  
WEATHER BUREAU  
WILLIS L. MOORE, Chief.

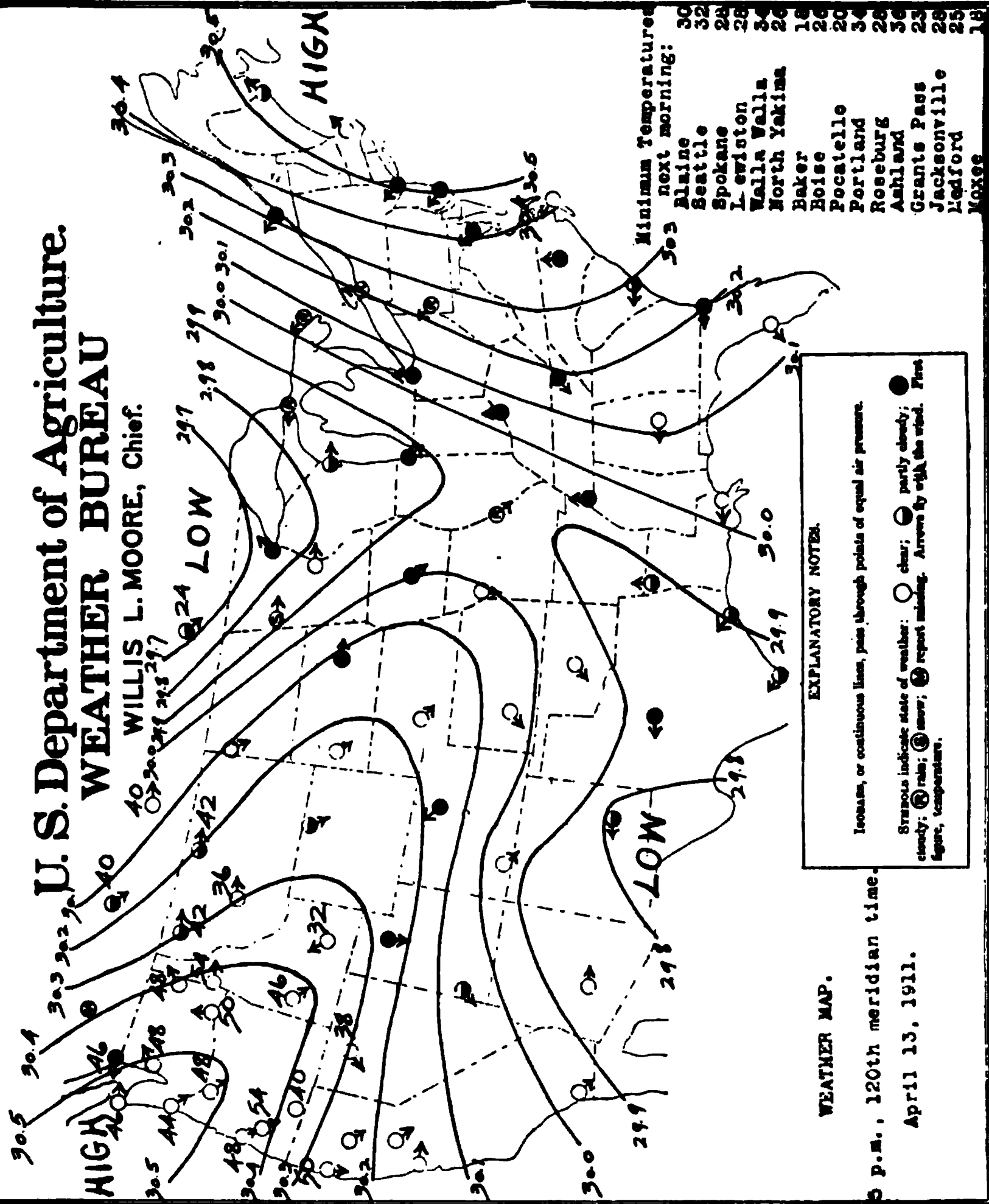
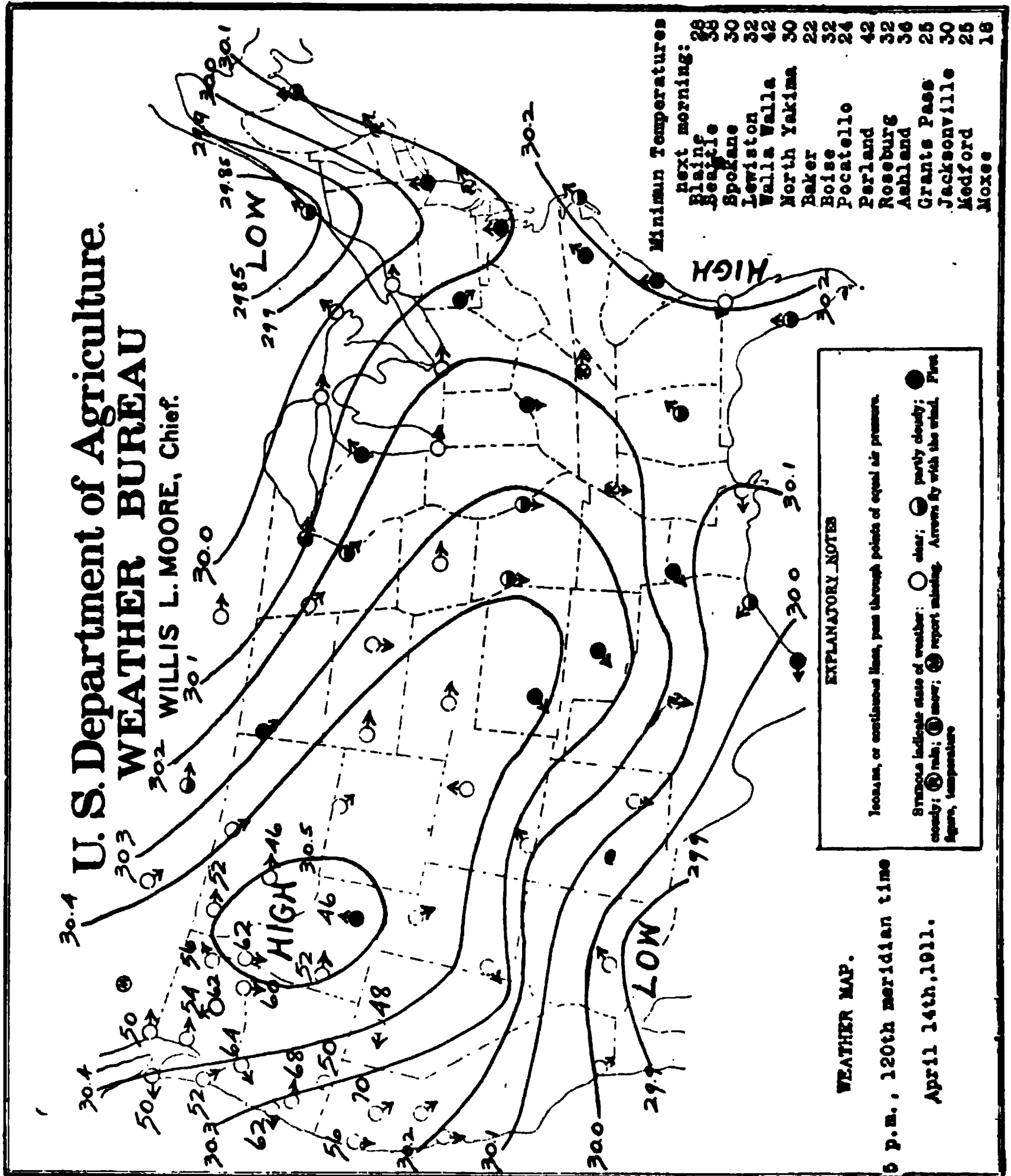


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CHART VI.













Bulletin No. 42.  
W. B. 467.

Issued March 5, 1913.

U. S. DEPARTMENT OF AGRICULTURE,  
WEATHER BUREAU.

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FORECASTING THE WEATHER.

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Prepared under the direction of WILLIS L. MOORE, Chief U. S. Weather Bureau,

BY

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WASHINGTON:  
GOVERNMENT PRINTING OFFICE.  
1913.

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From the

## PREFACE.

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In this bulletin the precise style of the textbook is purposely avoided, the object being to present some of the generally accepted facts and theories of meteorology in an elementary form and in a comparatively inexpensive publication to permit of a wide circulation.

No pretense is made of advancing new theories or ideas, except the one of popular education along these lines.

The basic matter, as taught by Profs. Moore, Davis, Hann, Mill, and other recognized authorities, has been clothed in the author's own verbiage. Technical terms have been avoided so far as consistent, and the work has been made elementary to the extent of adopting the form of direct address, in some instances, as being most impressive and effective.

The subject matter was, in the main, first published as a series of newspaper articles, and has since been revised to its present form by direction of Chief of Weather Bureau to meet the numerous demands that followed its first publication.

In the revision the author was materially assisted by suggestions from Mr. Edward L. Wells, Mr. Roscoe Nunn, and Profs. Alexander McAdie and J. Warren Smith.

THE AUTHOR.



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# FORECASTING THE WEATHER.

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## I. INTRODUCTORY.

If it were possible for a certain man to rise to a point every 12 hours where he could view the entire country from the Atlantic to the Pacific, from Canada to Mexico and the West India Islands, and if he could distinctly see the weather conditions over that entire territory and could watch the developments and movements of the storm areas, you would no doubt have a great deal of confidence in his ability to give out information regarding those conditions.

If on descending from one of his observations he should state that a storm area was moving in such a manner that its edge would pass near a given locality, you could readily understand that it would be a difficult matter to determine with certainty whether it would touch that particular locality or not.

Under such circumstances you would not call him a guesser if he should be in error 20 per cent of the time. You would say, "That man goes up where he can see all of the storms every 12 hours and can trace their movements continuously. He is able to outline ahead of each storm the greater portion of the territory that it will cover during the succeeding 24 to 36 hours. When the movements are somewhat irregular and the storms extend slightly beyond the territory outlined in some places and do not quite cover it in other places, it is a result that might reasonably be expected. On the average his information is accurate for more than four-fifths of the territory outlined, and such a high degree of success is surely not to be termed guess-work. If he can not tell with certainty regarding some localities then there is no use in others trying to do so, for he sees it all."

If any man could accomplish such a survey, what would his services be worth to the country? What would you think of the person who attempted to belittle his advice? Wouldn't it be plain to you that after obtaining a bird's-eye view of the whole country he would, at once, know more about the prevailing conditions than anyone else possibly could? Wouldn't you have a great deal of confidence in the opinions and advice that such a man offered, and wouldn't you defend him against all unjust criticism?

Difficult as such an achievement seems at first thought, the fact is that our Government maintains a weather service based on those same principles. The Weather Bureau of the United States Department

of Agriculture not only obtains, as it were, a bird's-eye view of atmospheric conditions over the entire country every 12 hours, but on special occasions it makes a survey of a severe storm area every 3 or 4 hours, following its movements and developments very closely until it spends its force or passes beyond the limits of observation.

When reading the forecasts and warnings issued by the Weather Bureau from time to time, you may not have realized that they were based upon such an elaborate system. Possibly you have been inclined to give equal confidence and credit to the opinions of certain individuals who talk mysteriously about the influence of the moon and the planets upon our weather, and who attempt to create the impression that the scientists of our Government Weather Bureau are groping in the darkness of ignorance.

It is the purpose of this pamphlet to explain how the seemingly impossible feat of obtaining an atmospheric survey of the entire country is accomplished, and to show that it is the only logical means of forecasting the weather. The following articles will also explain how the various phenomena that we experience in our daily weather changes are accomplished by physical forces in our atmosphere, and in a general way are well understood:

## II. HOW IT IS DONE.

Of course it is impossible for anyone to attain an elevation from which to view the whole country at once, but equivalent results are obtained by another process.

The Weather Bureau maintains telegraphic observing stations in all parts of the country, there being something over 200 of them in all, and observers at these numerous viewpoints, all acting simultaneously, are able to accomplish just as satisfactory a survey as would be obtained by one person at a single viewpoint if such a thing were possible.

Every 12 hours, precisely at 7.45 a. m. and 7.45 p. m., seventy-fifth meridian time, the observers in all parts of the country begin the work of observing and recording the weather conditions, each in his respective territory. The sky is observed and the clouds are classified; the barometer is read and corrections are applied to obtain the corresponding reading for sea level, so that all barometers may show the value for the same plane; the direction and the velocity of the wind are noted; the rainfall or snowfall, if any, is measured; the current temperature and the extremes since the last previous observation are taken from the several thermometers; the moisture content of the atmosphere is calculated; and all other phenomena, such as thunderstorms, fog, smoke, halos, etc., are carefully noted. Each observer then condenses the information he has secured into

a telegraphic cipher message of 4 or 5 words, that when translated or expanded into descriptive language would comprise from 30 to 50 words. This work consumes about 15 minutes, and is completed at all stations by 8 o'clock.

The messages are rapidly transmitted to main line telegraphic circuits, and are collected at the central office in Washington, and are also interchanged between many of the larger cities where forecasters are stationed. At these various centers, the messages are translated as fast as they are received, and the conditions are inscribed in their respective places on an outline base map of the country by means of figures, letters, and symbols.

The locations of the observing stations are indicated by small circles. Where cloudiness prevails the whole area of the circle is blackened; for partly cloudy conditions one-half of the circle is blackened; while the whole is left clear to represent clear skies. If rain is falling at the time of observation an "R" is marked in the circle, or an "S" for snow, as the case may be. Arrows are inscribed to fly with the wind. The barometer reading, temperature, wind velocity in miles per hour, and the depth of precipitation (rain or snow), if any, are written by the side of each station in figures. The precipitation areas are outlined and shaded. Red lines are drawn through points of equal barometric readings, and indicate atmospheric disturbances, the significance of which will be explained in later chapters. Blue lines are drawn through points of equal temperature, and the completed chart is known as a weather map.

The work, from observations to map making, is all conducted under such specific rules and regulations that the finished map is as complete a bird's-eye view for the experienced forecaster as if he had beheld all the conditions with his own eyes.

In less than 2 hours from the time the observations are taken, the various forecasters are, figuratively speaking, standing on eminences overlooking the entire country, and are prepared to give out information regarding the weather conditions in any section as well as to forecast the probable developments for a day or two in advance. By means of the map, the forecaster is enabled to anticipate the conditions for another State or for a distant city with nearly as high a degree of accuracy as he can for his own locality.

It should be borne in mind that the information that the forecaster gives out regarding the conditions in any portion of the country is derived from the reports of actual observations and is distinctly accurate and reliable. The forecasts that he issues represent his conclusions regarding the probable movements and developments for the time specified, but human judgment must necessarily contain some element of error.

However, as in the supposed case of the man with the bird's-eye view, we must conclude that if the forecaster with so much information before him can not always anticipate the movements and developments accurately, it would be useless for one not so equipped to attempt to excel him.

### III. A SHORT STUDY OF A WEATHER MAP.

If you have never studied the weather maps, but have merely glanced at them occasionally, thinking them to be only picture puzzles in which the lines are hopeless tangles and the figures and symbols represent nothing in particular, it will be interesting at this time to analyze a map and consider its prominent features.

At the end of this chapter is a map, selected because of its near approach to a theoretically ideal type that would well illustrate the general laws applicable to our atmospheric disturbances.

The isobars, or lines of equal barometer readings, form the most prominent feature of the map, as they locate the great centers of action. They are drawn for each tenth of an inch of variation. For example, the line marked "30.0" at each end passes through points where the barometer readings are just 30 inches. On one side of this line the readings are higher than 30 inches, and lines are drawn for each tenth of an inch increase until a center or crest is located and marked "High." On the other side lines are drawn for each tenth of an inch decrease until the center of the depression is located and marked "Low."

The real significance of barometer readings will be more fully explained in a chapter on "Atmospheric pressure," but for the present it will be sufficient to note that the isobars outline great atmospheric whirls or eddies.

Bearing in mind that the arrows are inscribed to fly with the wind, a careful inspection of the area having "Low" at the center will reveal the fact that the winds blow in toward the center, not directly, but spirally, just as water in passing down through a funnel flows around the center and approaches it gradually. You will further observe that the winds rotate about the center in a direction against the hands of a watch, face upward. Some places will be noted where the winds do not conform to the above rules, being temporarily deflected by local conditions. The more intense and energetic the disturbance becomes the more nearly will the wind movements conform to the general laws, as the forces in the great atmospheric eddy become strong enough to overcome local influences.

Now, if you will examine the area marked "High" at the center you will observe that the winds move in opposite directions from those in the "Low." In other words, they blow spirally outward

from the center. Also it will be noticed that the air currents flow in a compound curve from the center of the "High" toward the center of the "Low."

Since the surface winds, as indicated by the arrows, blow in toward the center of the "Low" from all directions, it becomes apparent at once that the air rises in the central area. Conversely, it is equally evident that the air is constantly settling down in the central area of the "High." The fact that the surface air currents flow from the center of the "High" toward the center of the "Low" suggests the idea that at some distance above the earth the rising air in the "Low" must flow toward the "High," and such indeed is the case.

It must not be imagined, however, that the interchange of air as noted above comprises the complete circulation of these areas, for if we were to map a larger territory we would discover adjacent disturbances with which the same relations are maintained.

The temperature conditions attending this atmospheric circulation are very interesting. Note that the freezing line (drawn through points having a temperature of 32° F.) begins in the extreme northeast, in central New Brunswick, and extends nearly due westward to a point north of the center of the "Low," and thence it sweeps southward nearly to the Texas coast, then northwestward into southern California, whence it bears northward nearly parallel to the Pacific coast line. A study of the wind directions with relation to this line will suggest some of the reasons for its trend.

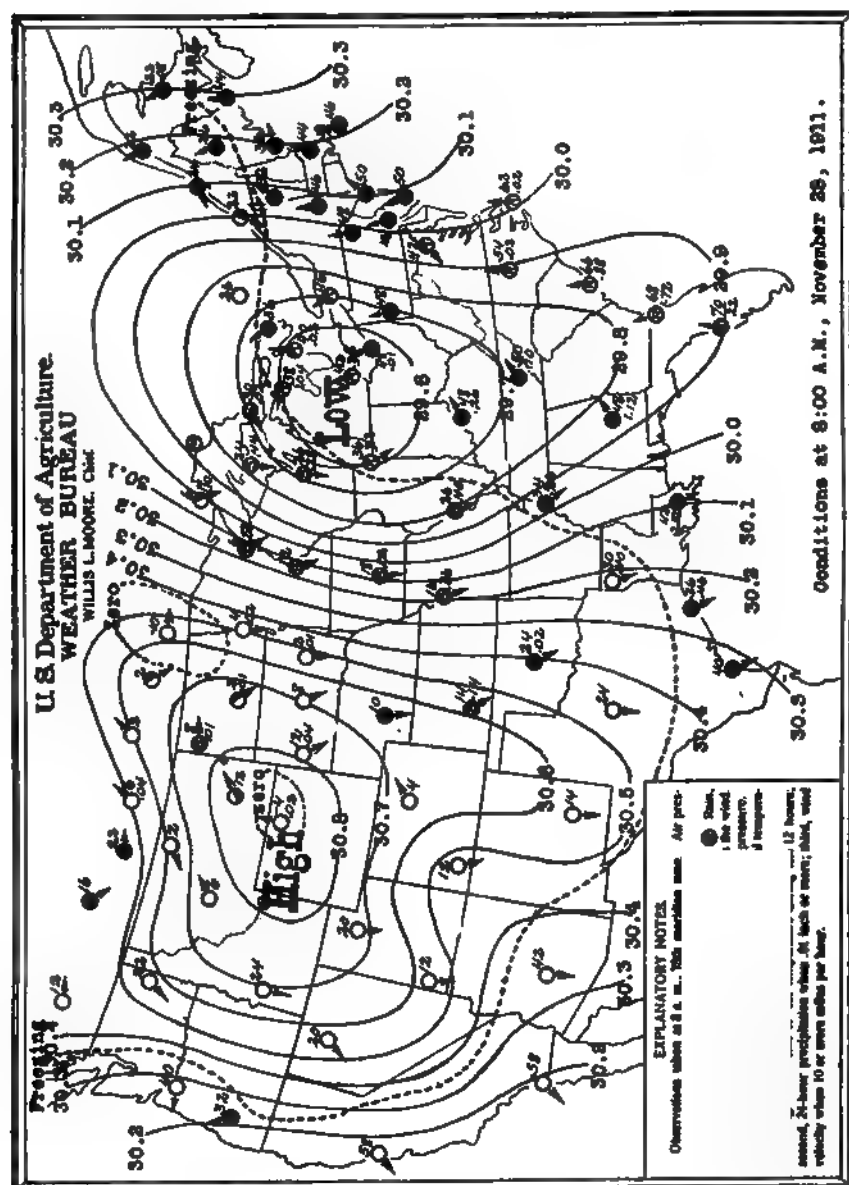
The weather conditions in these large atmospheric whirls are as remarkable as are the temperature conditions. Observe the prevailing cloudiness in the low-pressure area, bearing in mind that it is cloudy at the places marked with an "R" or an "S" the same as where the circles on the map are blackened. By way of contrast notice the clear skies over the greater portion of the high-pressure area.

Areas of high and low barometric pressure are constantly and successively drifting across the country from the west toward the east, and with the foregoing explanations the reader can readily understand the causes of our weather changes.

It becomes evident that while an area of low barometric pressure is drifting over a given locality the weather will ordinarily be cloudy, with a tendency to rain or snow, depending on the season of the year. The temperature will at first be comparatively high, followed by colder when the center of the area has passed and the wind shifts to a westerly or northwesterly direction. As the area of low pressure passes eastward and is succeeded by an area of high pressure, the temperature will continue to fall for a time and the skies will clear.

A rapid succession of high and low pressure areas implies frequent changes in weather and temperature conditions, while conversely

a sluggishness in the movements of these areas tends toward a prolongation of given types of weather.



#### IV. THE CONTRAST.

Thus far we have dwelt upon the similarity between the Weather Bureau map and a bird's-eye view of the country. Let us now contrast them and consider the numerous advantages that favor the map.



The person with a bird's-eye view could note the areas of cloudiness and sunshine, as we find them plotted on the weather map. He would necessarily be above the clouds and could not see where rain or snow was falling. Granting, however, that the types of clouds might enable him to closely approximate the precipitation areas, he would still be unable to determine the intensity or severity by measuring the amount of rain or snow fall. The Weather Bureau map gives all of this information accurately.

The bird's-eye view would enable the observer to determine the directions of the surface winds and to approximate their velocity in the clear areas by watching the drift of smoke, but in the cloudy areas he could only watch the cloud movements and estimate the surface winds from a general knowledge of atmospheric circulation. In high winds and gales he might catch occasional glimpses of heavy seas and of the destruction on land, but most of these effects would be obscured by intervening storm clouds. The observers of the Weather Bureau can see the cloud movements above and the effects of the storm underneath, and in addition they are enabled to measure the velocity of the surface winds.

The observer aloft could gain very little knowledge of the temperature. Under certain conditions he might see evidences of unusual extremes, but his knowledge would be crude and only approximate at the best. By means of the Weather Bureau map we may know exactly the temperature conditions in all parts of the country, and by comparison with previous maps we can see where they are rising and where they are falling. By taking a pencil and outlining the districts where the temperatures are rising and where they are falling, and then comparing maps, we can watch the movements of the warm and cold areas across the country just as clearly as we can that of the rain areas. By considering the amount of change that is taking place in any area, we can forecast for localities ahead of it as to whether the temperature change will be up or down and much or little.

A greater advantage than any or possibly all of those mentioned in favor of the weather map is the fact that it gives the barometer readings, thus accurately outlining the great atmospheric whirls or eddies and showing the slightest increase or decrease in energy. The man with the bird's-eye view could only approximate the territory covered by these disturbances, by means of noting the wind directions and the distribution of cloudiness, as explained in the preceding chapter. He could not detect moderate changes in energy or intensity.

Thus the observations, which are taken regularly every 12 hours by the Weather Bureau, are not only comprehensive bird's-eye views, but, more than that, they are complete and accurate surveys

of all the atmospheric conditions. When one comes to fully understand what the weather map represents, it takes on a new significance and an added importance. It is seen that the impossible bird's-eye view, as proposed in the first chapter, could not accomplish so much after all, and the private theories of the village weather prophet, which formerly seemed so plausible, become equally vaporous.

The distinctly practical and scientific methods of the Weather Bureau have no doubt appealed to the reader, but before making a closer analysis of the maps for the purpose of explaining more of the principles of forecasting, it will be advisable to study some of the more important characteristics of our atmosphere.

### V. THE ATMOSPHERE.

The atmosphere is composed of a mixture of gases and surrounds or envelops the whole earth. It is sometimes likened to a great sea of gases, at the bottom of which we live without the power to rise to the surface. The principal constituents are oxygen and nitrogen, in about the proportion of 21 per cent of the former and 78 per cent of the latter, the remaining 1 per cent being made up of five other gases. Water vapor, which is really water in a gaseous form, is always present but is a variable quantity. It occupies space independent of the other gases, and may comprise from 1 to 5 per cent of the total weight of a given volume of air.

The tendency for these gases to escape into space is overcome by the earth's attraction, and they rest upon its surface with about the same weight as a layer of water 34 feet in depth. In other words they press downward, and obeying the law of gases they also press in every other direction at sea level at the rate of nearly 15 pounds per square inch of surface.

We can not see the gases, and since they permeate all our tissues we do not feel their pressure except when they are in motion as wind. It used to be supposed that the atmosphere had no weight, and hence the saying "light as air."

Since the density of air at sea level is only about one eight-hundredth part that of water, it follows that the atmosphere would be eight hundred times 34 feet, or about 5 miles in depth if it were of the same density at all altitudes, which it is not. Gases are easily compressed, and therefore the layers near sea level have the greatest density because they are compressed by the weight of all that lies above. With increase of distance above sea level this weight is decreased steadily by the amount of air that is left below, and thus the pressure and density gradually diminish to nothingness.

So much of the atmosphere is compressed into the lower layers that one-half of it lies below an elevation of  $3\frac{1}{2}$  miles, although traces of its lighter gases have been revealed at an altitude of nearly 200

miles. Only one sixty-fourth of the atmosphere lies above an altitude of 21 miles, so we may realize that this gaseous envelope is relatively very thin as compared with the diameter of the earth.

The gases of the atmosphere are not in chemical combination, but are only mixed together, and according to Dalton's law each of them occupies space independent of the others. The lighter gases have the greater depth, and it is believed that hydrogen overcomes the earth's attraction and escapes into space. Nitrogen, which is the lightest atmospheric gas except hydrogen, is retained by the earth's attraction and forms what may be termed the outer limits of the atmosphere. Oxygen extends about four-fifths as high as the nitrogen, while water vapor and the heavier gases such as argon and carbon dioxide become very rare at the elevation of our highest mountain peaks.

The air holds in suspension many substances, such as bacteria and dust particles. We may sometimes think that it would be a great advantage to have all such foreign matter eliminated, but if so it is because we do not fully realize what the results would be.

Only a small portion of the bacteria are of the disease-breeding types, while many of the remainder are of real benefit to mankind. Bacteria are the chief factors in manufacturing all of the products of fermentation, and also they are the active agents that disintegrate the organic matters in the soil and prepare them for plant food.

The inanimate dust particles in the air are very important as they diffuse the sunlight and thus give a uniform illumination to the atmosphere. If the air were entirely freed from the dust and vapor particles, there would be a maximum of bright light and dense shadows.

## VI. HEATING AND COOLING OF THE ATMOSPHERE.

In this short treatise of the processes of the heating and cooling of the atmosphere, it is deemed unnecessary to explain the causes of the change of the seasons, or why a change of conditions is experienced with a change in latitude on the earth's surface.

It has been found that oxygen and nitrogen absorb very little of the solar radiation during its passage downward through the atmosphere, and that most of this function is performed by the water vapor although the dust particles are also a factor. Since the water vapor practically disappears at an elevation of about 6 miles, it follows that the absorption of heat is very slight beyond that distance, and even at elevations of 4 or 5 miles it is small as compared with that at lower altitudes. From the fact that one-half of the atmospheric gases and more than four-fifths of the moisture lie below an elevation of  $3\frac{1}{2}$  miles, it becomes evident that much more than one-half of the total absorption of solar heat takes place in these lower air strata.

Fully one-half of the solar radiation is ordinarily absorbed in its passage downward through the atmosphere, and of that which reaches the earth's surface a portion is absorbed while the remainder is reflected and is largely taken up during its outward passage through the moist lower air strata. The heat that is absorbed by the earth's surface is being constantly radiated and supplements that which is directly absorbed by the air. Also heat radiates more rapidly from a dry atmosphere than from a moist one, and thus as the moisture content decreases with increased elevation there is a corresponding increase in the rate of radiation.

In considering the conditions which affect the relative temperatures of the upper and lower air strata, we must admit another important factor which is of a dynamic character. When warm surface air is carried upward by rising currents the pressure upon it decreases steadily by the weight of air that is left below, and according to Boyle's law the gases must expand at such a rate that their density shall be constantly proportional to the pressure that they support. The work of expansion is performed against the force of gravity and consumes heat, thus lowering the temperature steadily at about the rate of  $1^{\circ}$  for every 270 feet of ascent. Conversely, if air from great altitudes is carried toward the earth the pressure upon it increases constantly and reduces its volume, but in this instance the work is performed on the air by the attraction of gravity, and thus raises its temperature.

By combining all these conditions it may be readily understood that the air strata near the surface are warmest, and that ordinarily the temperature decreases with increase of elevation. However, we sometimes have conditions known as inversions, in which the temperature increases with elevation for a few thousand feet. Also beyond the limits of the moisture content the temperature of the atmospheric gases is believed to be nearly constant at all elevations. The foregoing explanations account for the perpetual snow and ice on the tops of our loftiest mountains.

A water surface reflects a large portion of the heat that reaches it, while another large portion is used in the evaporation of moisture. The comparatively small amount that is absorbed warms the surface but little as it penetrates to a considerable depth. On the contrary, a land surface absorbs heat rapidly, reflects very little, and only a small portion is used in the evaporation of moisture. The portion that is absorbed does not penetrate deeply, and hence a given amount of heat will warm a land surface about four times as much as it will a water surface.

Inasmuch as the heat penetrates the water to a considerable depth, it is retained and radiates back slowly, while on the land it remains near the surface and radiates rapidly. A land surface heats and cools

faster than a water surface, and consequently the temperatures over the continents are subject to greater extremes and more rapid changes than those over the oceans. The difference between the conditions over the land and over the water are not so noticeable in coast districts because of the equalizing effects of the land and sea breezes, but there is a marked contrast between those over the interior of the continents and far out over the oceans.

From the foregoing it can readily be understood how very unequally the atmosphere is heated. The change of the seasons; the different latitudes with the consequent varying angles at which the sun's rays penetrate the atmosphere; the oceans and the continents; the mountains and the valleys; the sand deserts and the verdant fields; the clear skies and the varying cloud formations are all contributing factors to the unequal heating that keeps the atmosphere in continual motion.

## VII. CIRCULATION OF THE ATMOSPHERE.

Cold air is heavier than warm air under corresponding conditions, because heat expands the atmospheric gases and makes them less dense. We can see this principle illustrated in the hot-air balloon which rises because the superheated air in the sack is lighter, volume for volume, than the colder surrounding air, and it is forced upward in the same manner that a cork when released under water is forced to the surface. In general we may assume that the greater the difference in the temperature of adjacent volumes of air, the more energetic will be the movement or action to restore equilibrium, which accounts for the violent local disturbances in the atmosphere.

Bearing in mind that superheated air rises, and at the same time considering the temperature conditions that obtain on various portions of the earth's surface, we may reason out some of the movements that actual observations have proven to exist. In the equatorial belt the superheated air is constantly rising and flowing out on either side toward the poles. The cooler surface air that flows steadily in from either side and displaces the warm rising air constitutes the trade winds, which blow from the northeast in the Northern Hemisphere and from the southeast in the Southern Hemisphere.

The air that rises in the equatorial belt and flows out on either side can not move directly toward the poles on account of the convergence of the meridians. In other words, air can not move from all sides toward a common center, and in much the same manner that water flows around the outer portion of a whirlpool and approaches the center gradually, so the air passes around the earth at intermediate altitudes and forms a cyclonic circulation in each hemisphere that is most marked in the temperate zones. The direction of the circulation is determined by a force arising from the rotation of the earth



upon its axis, which deflects freely, moving particles to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

Underneath the eastward flow of air in the temperate regions, the unequal heating and the surface configuration break the circulation up into cyclonic and anticyclonic eddies which are shown as highs and lows on the weather maps. The extent to which the surface configuration enters into the formation of highs and lows is problematical, but it is known that the continent of Asia, with its different trend of mountain ranges from those of North America, is relatively free from such disturbances. The highs and lows are very shallow formations, being only about 2 miles in depth and sometimes more than 2,000 miles in diameter, and they are moved from west to east by the friction of the upper easterly air currents. Local disturbances, such as thunderstorms, tornadoes, waterspouts, and squalls, occur within the lows, while thunderstorms are not uncommon within the outer border of the highs.

The weather maps reveal the fact that the wind never blows in a straight line, although locally it appears to do so. All of the atmospheric movements are in whirls or eddies, large or small, the precise character of the whirl depending partly upon its size and partly upon surrounding conditions. All of the lesser disturbances, up to and including the high and low pressure areas shown on the weather maps, have a movement of translation in addition to the whirling or vortex circulation.

The most energetic air movements are tornadoes, which are local disturbances seldom more than 150 or 200 yards in diameter and which become so violent that the largest and strongest buildings are torn into pieces and strewn over their paths. In a tornado the depth is many times the diameter; so that the disturbance has a funnellike formation. In the larger disturbances, such as hurricanes and the large lows the area covered is relatively so great that they become very thin disks. The precise type of circulation must vary in these different formations, although it is cyclonic in each instance. A high may be likened to an inverted low, inasmuch as the circulation is the reverse of that in the low. The small dust whirls that we sometimes see in the street or over plowed fields illustrate the cyclonic principle of atmospheric circulation.

### VIII. ATMOSPHERIC PRESSURE.

The pressure of the air is the prime element in the study of all of its movements, and careful measurements of the pressure over large areas enable us to outline the great atmospheric disturbances. The air pressure is merely the combined weight of all the atmospheric

gases, and as previously explained it is equal to a layer of water about 34 feet, or a layer of mercury about 30 inches, in depth at sea level.

The gases press equally in all directions at any given point, and consequently an open vessel, or any substance which the air can freely permeate, sustains no appreciable strain because it stands in the gases in the same manner as does a boat in the water when it is filled and sunk. If an empty boat should be loaded to its capacity and no water allowed to enter it, then the pressure of the water on its sides and bottom would be equal to the combined weight of the boat and the load, and if the framework should not be strong enough to resist such a pressure the boat would collapse. Similarly, if we should take an air-tight tank or barrel at sea level, seal it and exhaust all the air from within, the outer walls would then be subjected to a pressure of approximately 2,000 pounds per square foot. When we exhaust the air from within a rubber bulb, the bulb collapses because it is not rigid enough to withstand the outside pressure.

We do not feel the pressure of the atmosphere under ordinary conditions because air permeates all the tissues of the body. However, if it were possible to exhaust all the air from the body of an ordinary sized man, thus leaving him under the full influence of the outside pressure, he would be crushed by a weight of more than 14 tons.

By reducing, or entirely removing, the air pressure from one direction, it becomes perceptible and measurable from the other directions. A mercurial barometer is an instrument designed to utilize this principle, and in its simplest form it consists of a glass tube about 34 inches in length and sealed at one end. The tube is filled with mercury to exhaust all the air and is then inverted, with the open end resting in a cup of mercury. When the mercury starts to flow out of the tube it leaves a vacuum above it, thus removing all the air pressure from above on the surface of the mercury that is in the tube. Enough mercury will remain in the tube to balance the atmospheric pressure on the exposed surface of the mercury in the cup. To be more exact we should say that the weight of the mercury in the tube balances the pressure on such a portion of the surface of the mercury in the cup as would equal in area a cross section of the glass tube. Thus an increase or decrease in the area of the exposed surface makes no difference in the results.

A barometer may be constructed by using water or other liquids instead of mercury, but since the atmospheric pressure is equal to a layer of water about 34 feet in depth it becomes evident that the glass tube would need to rise more than 34 feet above the surface of the water in the cup. The barometer was invented in 1643 by Torricelli, a pupil of Galileo.



A standard barometer consists of the above-described simple instrument incased in metal for better protection. A scale and vernier are attached near the upper end of the tube to facilitate accurate readings of the height of the mercurial column. An ivory point establishes zero of the column, or the point to which the surface of the mercury in the cup must be adjusted before reading. With these accessories the instrument becomes a fine balance, more sensitive and accurate than an apothecary's scales.

Aneroid barometers are designed for portability and are much less sensitive and accurate than the mercurial instruments. Instead of being true balances, they utilize the principle of the spring scale. The legends "Fair," "Change," "Rain," and "Stormy," often found on the dials, have no significance, and are commonly placed only on popular-priced instruments of medium or inferior quality.

Barometers, of either type, actually weigh the pressure of the atmosphere, and if their indications were expressed in pounds, ounces, drams, and grains instead of giving the height of the mercurial column, or its equivalent pressure, in inches and fractions of inches, the instruments would seem less mysterious to the average mind.

The passage of the great areas of high and low pressure across the country causes the mercury in the barometers to fluctuate slowly but continuously. The change is not so much as is commonly supposed but is very significant. In 40 years of Government weather records in Philadelphia, the highest barometer recorded is 30.96 inches and the lowest is 28.69, thus making an extreme range of 2.27 inches. This indicates a difference in pressure of about 160 pounds per square foot of surface, and is the same change as would be experienced in rising from sea level to an altitude of 2,150 feet. It is unusual for a barometer to change as much as an inch in 24 hours, and such a change indicates an energetic disturbance moving at a rapid rate.

#### IX. RELATION OF AIR PRESSURE TO WIND MOVEMENT.

Barometric gradient is a term used to express increase or decrease of pressure along a horizontal surface between two points, and upon its steepness depends the energy of a storm and the rate of the attendant wind velocities. Thus if a crest of high pressure was over Bismarck, N. Dak., with a barometer reading of 31 inches, and at the same time a center of low pressure was over Philadelphia, with a barometer reading of 29 inches, the barometric gradient between the two places would be said to be very steep. On mapping such conditions the isobars would be close together, the pressure formations would be intense and energetic, and high winds would prevail between the two centers.

As explained in a previous chapter, the air currents flow from regions of high pressure over certain curved lines toward regions of low pressure, and the barometric gradient determines the velocity of the wind. As the air currents approach a center of low pressure their velocity normally increases until they reach a point where the horizontal component is partly overcome by being deflected upward near the center. To understand this, you may observe, when pouring water through a funnel, that it moves faster near the center than it does toward the outer edge. This phenomenon is in accordance with a well known mathematical law.

In West Indian hurricanes the barometric gradients are usually very steep, which accounts for the destructive gales of wind that are developed. The relation of the velocity of the wind to the barometric gradient is sometimes likened to water flowing down an incline, but the illustration is not in all respects a good one.

#### X. WATER VAPOR.

Heat breaks water up into its molecules, and imparts to it many of the properties of a gas. In fact, water vapor is commonly defined as being water in a gaseous state. It is different from most gases in that it can change from a gaseous to a solid form, as from vapor to frost, without passing through the liquid state, and conversely, ice and snow may pass directly into water vapor without becoming liquid.

The heat energy that is required in the process of evaporation is rendered latent, or imperceptible by any means, until the vapor is condensed back into visible water particles, when it is freed again as sensible heat. It is therefore easily understood that evaporation from a moist surface has a cooling effect, and the more rapid the evaporation the faster will the heat energy become latent and the greater will be the cooling effect.

We commonly speak of moist and dry air with the implied meaning that the gases of the atmosphere soak up the vapor much as a sponge would take up water, and the matter is probably understood in that light by many; but the fact is that the vapor occupies space practically independent of the other gases. At any given temperature, the same amount of vapor can be diffused through a vacuum as through an equal volume of air at sea-level pressure.

The amount of vapor that can be diffused through a given space is governed almost entirely by the temperature, and the amount of moisture can be practically doubled with each increase of  $20^{\circ}$  within the ordinary ranges experienced in the free air. Thus by raising the temperature from zero to  $80^{\circ}$ , the capacity of a given space for moisture is increased almost sixteenfold.

Water vapor is invisible until the space which it occupies is supplied to the limit of its capacity at that temperature, after which any additional moisture becomes visible as steam, fog, or cloud, which are all really identical in formation. A reduction of temperature under such conditions will also cause condensation by reducing the capacity of the space for holding vapor, which is virtually the same as adding vapor beyond the capacity.

If we could look into the boiler of an engine nothing would be visible above the surface of the water which it contained, although the pressure of the vapor might be 150 pounds or more to the square inch. The temperature in the boiler would be very high, and the instant that the vapor escaped from it into the free air it would be condensed by its expansion and sudden cooling and would become visible. When vapor is beginning to condense into visible fog, a rise in temperature will cause it to again become invisible.

Night fog is caused by the radiation of heat from the surface of the ground and from the adjacent air strata until the temperature falls to a point where a portion of the atmospheric vapor condenses. The temperature at which such condensation begins is known as the dew point, and at that time we say that the atmosphere is saturated. Saturation occurs in a dense fog, which is like a cloud at the surface of the earth instead of at a higher elevation as usually seen.

At times there may be present in the atmosphere only one-half or three-fourths of the amount of moisture needed for saturation, and when this amount is considered with relation to the amount necessary for saturation it is termed relative humidity. Thus we may say that the relative humidity is 40 per cent, meaning that two-fifths, or 40 per cent, as much moisture is present as would be needed for saturation at that temperature.

The rate of evaporation from any water or moist surface is mainly controlled by two factors namely, the air movement and the relative humidity. Water vapor exerts a certain pressure that is not produced by the other gases on a water surface, and this pressure has a controlling effect on the rate of evaporation. When saturation occurs the vapor pressure is such that evaporation becomes almost nothing, and at such a time if the air were to become quiescent it is probable that evaporation would cease entirely. Thus during a period of high temperature and light winds the conditions become oppressive if there is much moisture present, or, in other words, if the relative humidity is high, because at such times the perspiration is evaporated from our bodies slowly and we do not experience the cooling effects that accompanied a drier atmosphere or stronger winds, with the rate of evaporation much greater.

The condensation of water vapor into visible particles seems to require some solid substance upon which to collect. Thus you have

noticed the moisture condense on the outside of a pitcher of ice water. The cold pitcher reduces the temperature of the adjacent air below the dew point and the surface of the pitcher forms the solid substance upon which the moisture can collect.

When condensation takes place in the free air the dust particles act as the substance upon which the moisture can collect, and each minute water globule contains a dust mote. This is true whether condensation takes place as fog near the earth's surface or as clouds at high altitudes. Atmosphere entirely free from dust has been artificially cooled far below the dew point without condensation, but upon admitting a little puff of dust-laden air the moisture condensed into fog immediately. The necessary dust particles are carried up into the higher altitudes by the same air currents that carry up the water vapor, and air currents carry dust from the continents across the oceans, thus facilitating the condensation of water vapor in all parts of the globe.

At night in summer time the radiation cools the surfaces of vegetation below the dew point of the adjacent air, and the moisture collects on the leaves in precisely the same manner as it does on a pitcher of ice water. Very little, if any, moisture is seen on the pavements or other solid substances which absorb so much heat during the day that they do not cool below the dew point at night.

When condensation takes place on any surface the temperature of which is below the freezing point, it forms frost instead of dew. Remember that dew does not "fall" according to the common expression, but the moisture collects from the air that comes directly into contact with the cooled surfaces.

## XI. PRECIPITATION.

Rain, snow, hail, and sleet are all comprehended in the general term "precipitation," and their differences in character are due to the conditions under which they are formed. Thus, while dew, frost, and low fog are caused principally by the cooling from radiation, the formation of rain, snow, hail, and sleet is due to the process of cooling that ordinarily attends the expansion of rising air currents.

If the dust particles in the rising air are plentiful and the ascent is not too rapid, the moisture will condense on the dust in extremely small globules, which, being very light, will be supported by the rising air and will float along as clouds instead of falling to the earth as a mist. If the ascent should be rapid and the dust particles few, a larger amount of water will collect around each dust mote and the globules will become heavy enough to fall through the rising air currents to the earth. Thus raindrops form mostly in the upper portions of the clouds, where the cooling is greatest and where the dust particles are fewest, and then in falling through the clouds they collect more moisture and increase in size.

If the vertical air currents are intermittent and quite strong, as in a thunderstorm, the raindrops are sometimes carried back and forth through the clouds, accumulating the smaller water globules until they become very large. The condition of the atmosphere between the clouds and the earth with regard to moisture is also a considerable factor in determining the size of the raindrops. When this atmosphere is almost saturated the raindrops may increase in size while passing through it, while conversely a warm dry atmosphere may evaporate the rain before it reaches the earth. It is not an uncommon occurrence on a warm summer afternoon to note rain falling from a cloud and gradually evaporating until it can no longer be followed by the eye.

The difference between rain and snow is similar to that between dew and frost. When condensation in the free air occurs with the temperature below freezing, the vapor passes directly into the form of minute ice crystals without first forming water globules. Hundreds of these ice crystals unite to form a snowflake. When snowflakes are examined under a microscope they are found to form regular six-sided figures in an almost endless variety of geometrical designs. Under ordinary conditions it takes from 8 to 12 inches of snow to equal in moisture 1 inch of water.

The formation of hail has never come under direct observation as has that of dew, fog, frost, rain, and snow, and consequently our knowledge of the process is largely theoretical. The conclusions in this respect are based upon two phenomena. First, true hail occurs only in warm weather and is usually an accompaniment of thunderstorms where strong vertical air currents are present. Second, on cutting a hailstone through the center it is found to be made up of concentric layers of snow and ice.

It is therefore reasoned that the hailstone formation is begun by a raindrop being carried to such an altitude that the expanding air about it is cooled below the freezing point, and therefore the drop is frozen, then falling back into the warmer stratum of cloud and rain, where its cold surface immediately collects a coating of water, only to be carried by another gust of rising air back into the higher altitudes to be frozen. This process is continued by the intermittent gusts of rising air until the hailstone becomes so large that it can no longer be supported aloft, when it falls to the earth. Sometimes several hailstones touch and freeze together, falling to the earth as a large irregular chunk of ice.

During the winter season rain sometimes forms in a stratum of air where the temperature is slightly above freezing and afterwards falls through colder air strata and reaches the earth in the form of frozen rain drops or ice pellets. This form of precipitation is not hail but sleet. Sometimes the raindrops and ice pellets are mixed, with the temperature practically at the freezing point, and if the surface air



temperature is below freezing a coating of ice is formed on every exposed surface.

The processes of condensation and precipitation are on such a stupendous scale in nature, even during the progress of a light shower, that all the artificial forces controllable by man are puny by comparison. The stories sometimes circulated regarding the accomplishments of so-called rainmakers fail to take into account the general atmospheric conditions prevailing at the time. When showers follow the rainmaker's operations and he therefore claims success the weather map almost invariably shows rain over too large an area to have been the result of local agitation, no matter how seemingly violent that agitation may have been. A clear sky, locally, at the beginning of the operation does not argue that the showers which may follow are the result of the rainmaker's efforts.

## XII. WEATHER FORECASTING.

You can now begin to apply to the weather map the principles learned in a cursory study of the elements, and by so doing you can begin to anticipate storm movements and developments. Many changes occur in the atmospheric disturbances during their progress across the country, owing to the continual shifting of their relative location with regard to mountains, lakes, the seashore, or to extensive dry plains. It must be remembered that the barometric pressure areas are only formations through which the atmosphere circulates and that they do not carry a given quantity of air with them across the continent.

Weather forecasting consists in watching the storm movements and developments by means of the weather maps, in anticipating the changes that will take place in them, in estimating the expanse of territory that will be covered and the time that given points will be reached, and thereby determining the weather conditions that may reasonably be expected in each locality during the ensuing 36 to 48 hours. A chart, showing average storm tracks and average daily movements in the United States, will be found at the end of this chapter. .

About 60 per cent of the areas of low barometer in the United States are first seen over the extreme northwestern portion of the country, and thence they move eastward along the northern border, across the Great Lakes, and finally pass off the north Atlantic coast. From your knowledge of the elements you can now reason out the changes that may be expected to occur within these disturbances during their progress over this northern route.

When a low-pressure area is central over Idaho, for example, you can readily understand that the precipitation within it will ordinarily be light, inasmuch as the air that circulates through it flows in from comparatively dry regions. The air currents from

the Pacific rise rapidly as they flow inland and, cooling by expansion, they are deprived of a large portion of their moisture on the western side of the Cascade range of mountains.

When the center of the disturbance has moved eastward across the Rocky Mountains the rainfall begins to increase in the eastern side of the area, occasioned by the greater quantity of moisture in the atmosphere that flows in from the central valleys and from the western portion of the Lake region. From thence eastward the storm usually increases in energy as it reaches into lower altitudes and moister regions, but ordinarily these disturbances do not cause heavy or excessive precipitation.

The low-pressure areas that are first seen over the southern plains, and those that move into the Southern States from the Gulf of Mexico, generally drift northeastward and pass off the north Atlantic coast. They are usually more intense and energetic than the disturbances that cross the country along the northern border because they move through moister and warmer regions.

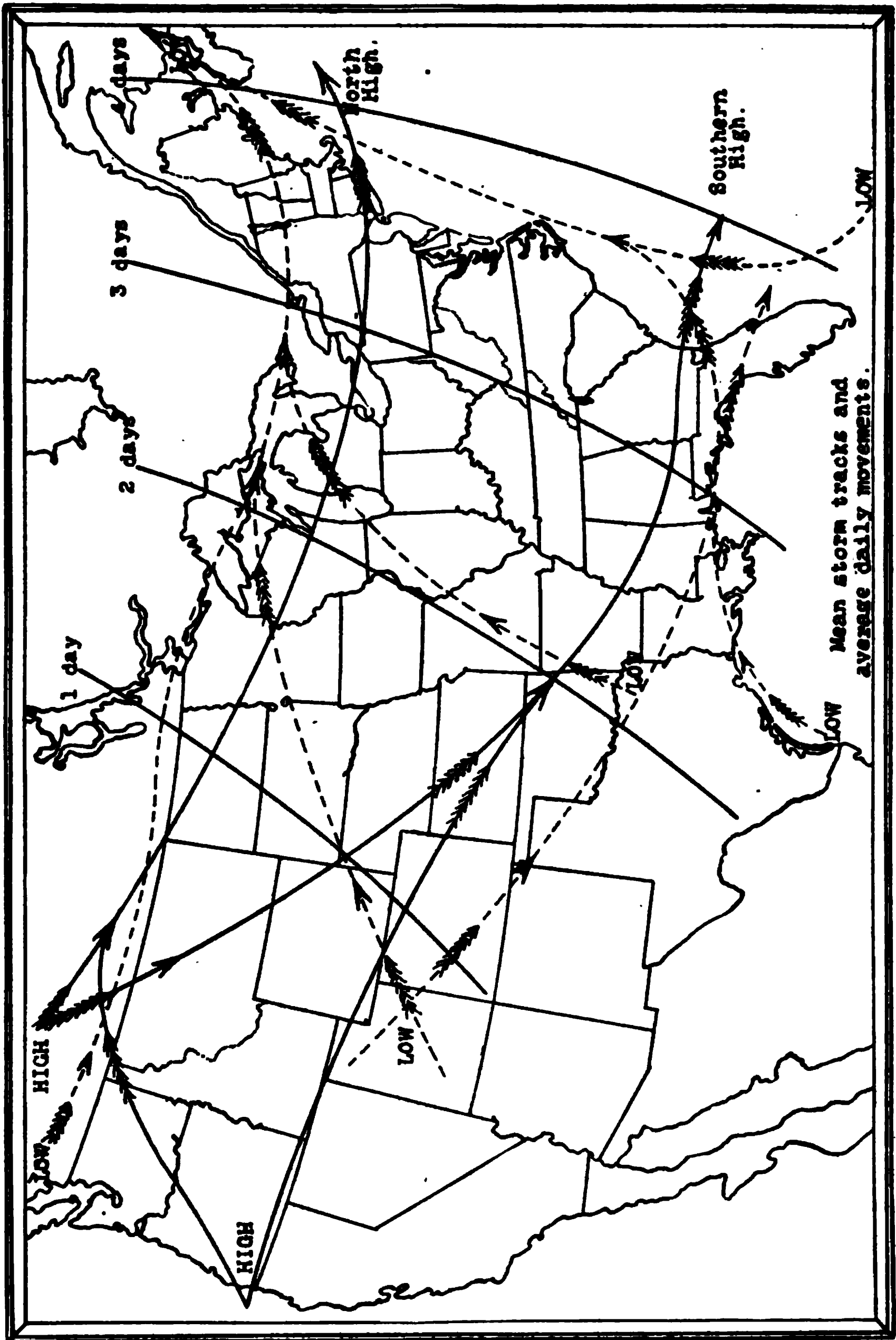
Now conceive a well-developed storm to be central over northern Texas and drifting toward the New England States. During the entire time that it is crossing the great central valleys it is drawing warm air currents from the Gulf of Mexico heavily laden with moisture. The rainfall attending such storms is generally heavy, and their passage sometimes breaks up severe droughts in the great corn and wheat belts. As these storms move farther northeastward they pass between the Great Lakes and the Atlantic coast, and the decreasing supply of moisture from the Gulf is largely counteracted from these other sources and heavy rains may and generally do continue.

The storms that move up from the Tropics to the south Atlantic or Gulf coasts of the United States during the late summer or early autumn are termed "hurricanes." They are usually smaller in area than the storms which form on the continent, but are more intense and energetic. When first seen in the Tropics, they have a tendency to move slowly northwestward, and to continue in that direction until they reach the latitude of the Gulf coast, when they recurve to the northeast unless prevented from doing so by an area of high barometric pressure. On recurving they usually increase their rate of movement and sometimes sweep over our entire Atlantic coast in less than 48 hours.

When a hurricane makes its appearance in southern waters it is necessary to receive frequent reports from all observation points in its vicinity and watch its movements very closely in order to issue warnings ahead of it. Before the storm-warning system of the United States Weather Bureau was developed to its present high degree of efficiency these storms used to strew the Atlantic and Gulf coasts with the wrecks of vessels. Although the number of vessels



engaged in coastwise trade has increased considerably, the number of wrecks is but a small fraction of those of former times.



During the last few years the Weather Bureau has received reports by wireless telegraph from several cooperating vessels and its survey of the tropical regions has been much more complete than formerly.

## XIII. WEATHER FORECASTING (CONTINUED).

Cold waves usually accompany energetic areas of high barometric pressure following those of low pressure. They are confined principally to the winter months, when temperature changes are most sudden and pronounced. If a rapid fall in temperature occurs in summer it is usually from a point much above the normal to a point as much below the normal without injurious conditions at any time, but in winter a fall from the freezing point to a temperature near zero would do much damage unless ample warnings were issued so as to allow the protection of perishable products.

You have learned that the areas of high barometric pressure make their first appearance in the far northwest, usually over the northern Rocky Mountain plateau, and that they move either eastward across the Northern States or else southeastward to the lower Mississippi Valley, and then recurve to the eastward or northeastward. You have also learned that in these areas the air settles down cool and dry from the higher altitudes, or, more correctly speaking, the air settles down in the central portion of the area, while away from the central portion all the lower air currents have a slight deflection downward.

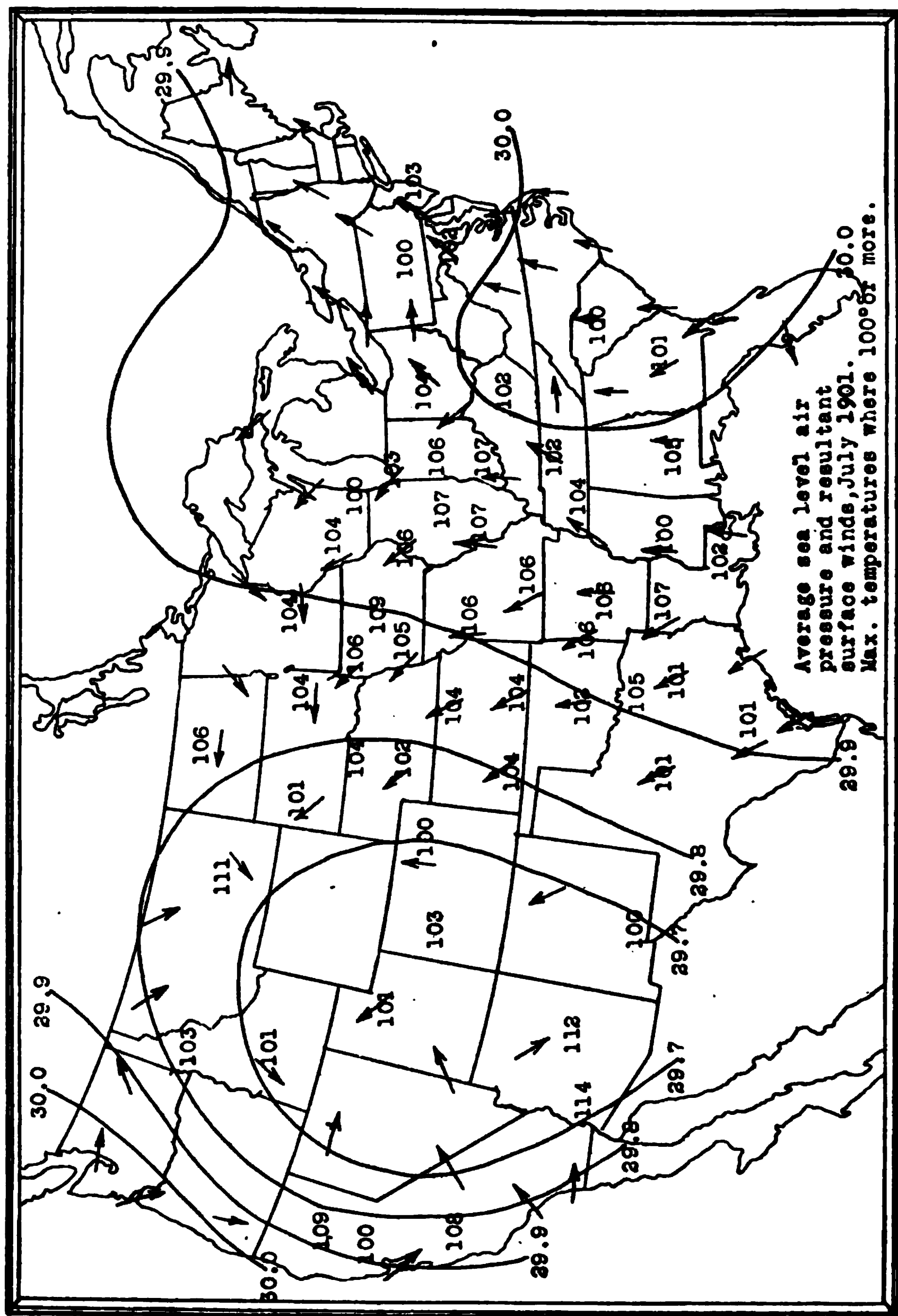
During the winter season, if a high pressure area appears in the far northwest, with a low area over the Southern States, the low area will usually move eastward and northeastward, while the high area, with its attendant low temperatures, will sweep southward to the Gulf coast. Should there be no well-defined area of low pressure over the Southern States, the high area would be more apt to pass eastward over the northerly route. A high-pressure area that is not preceded by a low will not cause so great a fall in temperature in proportion to its intensity as one that is thus preceded.

The high-pressure areas that move from the Northwest into the Southern States usually decrease in energy on recurving to the eastward or northeastward, and so reach the Atlantic States in a modified form that seldom causes a marked fall in temperature. When cold waves occur in the North Atlantic and New England States they follow closely upon the passage of a center of low pressure, the high-pressure area generally moving eastward or southeastward from the upper Lake region. Under certain conditions a cold wave may occur at the rear of a center of low pressure, with no well-defined high-pressure area following it, but in any event an increase in barometric pressure accompanies every cold wave.

Mention has been made of the tendency of the air currents to flow from a crest of high pressure toward a center of low pressure, and it is therefore plain that when a cold area of high pressure is following a low from the Northwest the temperature will begin to fall at any



pressure will sometimes stagnate over the South Atlantic States or just off the coast, while a low moves into the upper Mississippi Valley and the upper Lake region. Under such conditions the air cur-



rents that flow from the central portion of the high area toward the low move along the surface and, steadily increasing in temperature, they gather up moisture over their course and cause abnormally

warm and humid conditions in the Ohio Basin and in the Middle and North Atlantic States. If the areas are large, with the crest of high pressure off the south Atlantic coast and the center of the low in the far Northwest, the abnormally high temperatures will cover all the great central valleys.

The month of July, 1901, marked the most intense period of abnormal heat from the Atlantic coast westward to the Rocky Mountains that has been recorded in the United States. The average barometric pressure for the month serves to illustrate the conditions that caused the intense heat much better than a map for any specific date, and a chart showing the average pressure for that period has been taken from the Monthly Weather Review and adapted to this purpose.

#### XIV. WEATHER FORECASTING (CONTINUED).

In our Northern States much the greater portion of the rainfall occurs on the eastern and southern sides of low-pressure areas. The heaviest rains in the Southern States are usually caused by low-pressure areas moving in from the Gulf, but rain often occurs when an area of high pressure moves down from the north, the cool descending air currents appearing to run under the moist lower air strata which are raised, cooled by expansion, and a portion of their moisture condensed and precipitated.

The areas of high and low barometric pressure are more energetic, excepting the West India hurricanes, and move across the country at a more rapid rate during the winter than during the summer season. The rate of movement of a storm area across the country should not be confused with the wind velocities within its boundaries, for sometimes a storm that is moving quite rapidly will be suddenly checked and will increase in energy as a consequence, thus developing higher wind velocities than when its movement of translation was greater. The West Indian hurricanes travel very slowly so long as they follow the westerly course, but the wind velocities generated within them are usually destructive.

The rate of movement of storm areas is seldom steady and uniform for any considerable length of time, but the average rate is about 37 miles per hour in winter and 22 miles per hour in summer. They travel faster across the Northern States than they do in the southern portion of the country.

High-pressure areas have a greater tendency to turn southward while crossing the great central valleys in the winter than they have during the summer. The larger and better formed all atmospheric disturbances are, the easier it becomes to anticipate their movements and developments and thereby to forecast ahead of them. It is when a map shows several partly developed areas, or when their movements become sluggish, that forecasting becomes most difficult.

So long as a disturbance keeps moving the forecaster has a basis for his calculations, but when it becomes stationary he has no means of determining when it will start to move again.

During midsummer when the pressure formations are least energetic there is a tendency for conditions to become localized, and we have showers instead of general rains. When conditions indicate showers a forecast must be made for them, and while they may cover much the greater portion of the territory for which they are forecast, still there will be many places where no rain will occur and where the forecaster will be blamed for missing his calculations.

When conditions are such as to indicate only a few widely scattered showers, the better policy will be to forecast fair weather, as that condition will no doubt prevail over three-fourths of the territory covered by the forecast. In those scattered localities where showers occur the forecaster will again be blamed for an unpardonable blunder.

In estimating the resultants of storm movements and developments it is necessary for the forecaster to estimate the intensity and effect of a great many forces, and to perform the work with great rapidity. He must be continually on the alert if he would make a high percentage of successes in his work.

#### XV. FORECASTING FROM LOCAL INDICATIONS.

The ability of mariners to forecast weather changes from local observation is proverbial. This is not because the signs are so much more pronounced over the ocean than over the land, but is primarily because the mariner has no other source of information and must learn to interpret their significance. On land a heavy storm is not so often a matter of life or death, and consequently while most people recognize a few weather signs they rarely follow them out in a systematic manner to determine their reliability.

About three-fourths of the population of our country can be readily reached with the information disseminated by the United States Weather Bureau by means of its publications, by the daily papers, and by telegraph and telephone. This advice being more reliable than local signs, has practically supplanted them in all the districts covered, and many lines of business and many social functions are planned and conducted accordingly.

Weather changes are not usually definitely heralded by local signs for a period longer than 12 hours in advance, while many local storms give scarcely an hour's notice of their coming. Very few indications apply with equal force to all parts of the country. Conditions along the Pacific coast differ materially from those along the Atlantic coast, the Gulf coast, or the interior of the continent, and in the interior there is a great difference between conditions in the Rocky

Mountain region and the central valleys or the Great Lakes. Many signs which might be considered reliable in the Ohio Valley would be valueless in the drier districts of the far Southwest.

In order that one may formulate a series of signs that will be distinctly applicable to the locality in which he lives he should proceed in a careful and systematic manner to record and correlate his observations. Weather proverbs will not be found to be generally applicable, and only those which when analyzed are found to be based on scientific fact will be worth considering.

Signs pertaining to the condition of the atmosphere, the appearance of the sky, the character and movements of the clouds, and the direction and force of the winds are, generally speaking, all that are worth testing out for one's particular locality.

Proverbs regarding the actions of birds and animals are usually of little value. Marked changes in the atmospheric conditions are responsible for their peculiar antics, and these same changes are generally preceded by reliable signs, if one learns to observe and interpret them.

Sayings which pertain to the moon and the planets are entirely foreign to the subject, and those which apply to forecasts for coming seasons are wholly without foundation. Peculiar growths and developments in vegetation are the result of weather conditions that have passed and have no connection with those to come. The character of the muskrat's house or the beaver's dam is the direct result of the stage of the water at the time the structures were made.

By mapping the entire Northern Hemisphere the Weather Bureau is enabled to forecast general conditions for a week or 10 days in advance with a creditable degree of accuracy, but at the present time there is nothing known which justifies any person in venturing forecasts for longer periods. Thus, the person who would learn to forecast from local observation will do well to confine his efforts to the detection of weather changes a few hours in advance. It is reasonable to expect a continuation of observed conditions at any time until there are indications of a decided change.

Inasmuch as the barometric pressure is the main feature of the weather map, and is of as much importance to the forecaster as all of the other information combined, it is equally as essential that the local observer should be equipped with some means by which to detect changes in atmospheric pressure. The pressure changes in connection with the wind direction will give him the key to the situation. There are certain wind-barometer indications that are applicable to all localities in our country, and the following statements are published on all Weather Bureau daily weather maps:

When the wind sets in from points between south and southeast and the barometer falls steadily, a storm is approaching from the west or northwest, and its center will



pass near or north of the observer within 12 to 24 hours, with wind shifting to northwest by way of south and southwest. When the wind sets in from points between east and northeast and the barometer falls steadily, a storm is approaching from the south or southwest, and its center will pass near or to the south or east of the observer within 12 to 24 hours, with wind shifting to northwest by way of north. The rapidity of the storm's approach and its intensity will be indicated by the rate and the amount of the fall in the barometer.

On account of its portability and ease of handling, an aneroid barometer is best suited to the needs of the local observer, and a reliable instrument can be purchased for \$10 to \$15. The legends, if any, on the face of the instrument should be entirely disregarded, remembering that even if at times they should seem to be applicable to a given locality, a change in altitude of a thousand feet would throw them to a decidedly different relative position on the scale.

The brass pointer should be set over the indicating hand on the dial of the instrument morning and evening and the change in atmospheric pressure noted for each 12-hour period. The barometer should be read and the wind direction and force noted when precipitation begins and again when it ends. The character and movements of the clouds should always be observed, as they are the only indicators of the conditions of the atmosphere at higher altitudes.

A series of such observations, when compared and classified, will soon reveal certain well-defined relations that will enable the observer to begin a list of reliable local signs. The list will increase with the period of observation, and established rules will be modified by noting the most common exceptions. Some signs which are reliable for one season of the year will need to be materially changed in order to apply to the conditions of a different time of the year. When a local sign has been thoroughly tested and found to be reliable in a large percentage of cases the observer should then record it permanently for the benefit of future generations in that locality. Each well-established rule will be of incalculable value to that community in times to come.

The observer should remember that all weather changes are the results of physical conditions occasioned by the unequal heating of the atmosphere and modified by the locality and the character of the surrounding territory. Everything savoring of astrology, of superstition, or of the mysterious in general should be entirely rejected, and he should proceed with his work on a purely physical and scientific basis.











W. B. No. 498.

Issued June 7, 1913.

U. S. DEPARTMENT OF AGRICULTURE,

WEATHER BUREAU.—BULLETIN 43.

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# THE RIVERS AND FLOODS OF THE SACRAMENTO AND SAN JOAQUIN WATERSHEDS.

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Prepared under the direction of WILLIS L. MOORE, Chief U. S. Weather Bureau

BY

NATHANIEL R. TAYLOR,  
LOCAL FORECASTER.

WASHINGTON:  
GOVERNMENT PRINTING OFFICE.  
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## LETTER OF TRANSMITTAL

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UNITED STATES DEPARTMENT OF AGRICULTURE,  
WEATHER BUREAU, OFFICE OF THE CHIEF,  
*Washington, D. C., February 4, 1913.*

The honorable the SECRETARY OF AGRICULTURE,  
*Washington, D. C.*

SIR: I have the honor to transmit herewith a paper by Mr. Nathaniel R. Taylor, local forecaster in charge of the local office of the Weather Bureau at Sacramento, Cal., on "The Rivers and Floods in Sacramento and San Joaquin Watersheds."

I recommend the publication of this paper as a bulletin of the Weather Bureau.

Very respectfully,

II. E. WILLIAMS,  
*Acting Chief United States Weather Bureau.*

Approved:

JAMES WILSON, *Secretary.*



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FIG. 1 - The Sacramento and San Joaquin watersheds.

# THE RIVERS AND FLOODS OF THE SACRAMENTO AND SAN JOAQUIN WATERSHEDS.

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By NATHANIEL R. TAYLOR, Local Forecaster.

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## INTRODUCTION.

This paper will be devoted to a discussion of some of the causes that modify stream flow in the Great Central Valley of California and to the tabulation of such river and rainfall data as are available in connection with flood periods, with notes on the various floods that have occurred since 1849, more especially those in the Sacramento watershed. A brief description of the larger streams and their watersheds will be given, together with distances between important points on the main rivers and their larger tributaries.

Much of the information relative to floods in the early days in the city of Sacramento has been gleaned from the History of Sacramento County, Cal., by Thompson and West, and by a perusal of the old files of the Sacramento newspapers, the Bee and the Record Union.

Information relative to the floods of the Feather and the Yuba Rivers, and to the condition of these streams during the past two decades, has been kindly furnished by Mr. W. T. Ellis, president of the Marysville Levee Commission, who has made an exhaustive study of floods in the watershed of the Feather-Yuba, and, who, more than any other official, is responsible for the almost impregnable levee system that has made Marysville practically immune from future floods.

Mr. W. E. Meek, of Antioch, Cal., and others, with whom the writer has discussed conditions in the island districts, have kindly supplied much valuable information, which has never before been published, relative to floods in the delta lands of the Sacramento and San Joaquin Rivers.

In addition to the records of the Weather Bureau, from which river and precipitation data have been taken, a study of the various Water-Supply Papers of the water resources branch of the United States Geological Survey has been the means of securing much of



the information regarding elevations and descriptions of stream sources in the high Sierra.

An article published in the American Society of Civil Engineers, by W. B. Clapp, E. C. Murphy, and W. F. Martin, has been of material assistance to the writer, especially with respect to the areas and capacities of the numerous flood basins of the Sacramento Valley.

The map, tabulations, and hydrographs printed in connection with this paper are the work of Mr. Hermann J. Andree, assistant observer, United States Weather Bureau.

While the records of the Weather Bureau contain river gauge readings at several points on the Sacramento River as early as 1875, and on the San Joaquin River since 1896, it was not until May, 1906, that a thorough river service was inaugurated, which included stations at all strategic points, not only on the Sacramento and San Joaquin Rivers but on all important watercourses that feed those streams.

The work of reorganizing the river service of the Great Central Valley was performed by Mr. James H. Scarr, local forecaster, United States Weather Bureau, under the direction of Prof. Willis L. Moore, chief of the bureau.

The length of the Great Central Valley of California is about 500 miles. It varies in width from a few miles at its northern limits, near Redding, to 50 or 60 miles in the Sacramento Valley, to as much as 125 miles in parts of the San Joaquin Valley. It is bounded on the east by the Sierra Nevada and on the west by the Coast Range. These ranges meet on the north at Mount Shasta and again on the south, where they are connected by the Tehachapi cross range, the whole being shut in, except for a narrow opening in the Coast Range at San Francisco, through which its drainage reaches the Pacific.

Probably in no other part of the United States are river conditions so complicated as in the section under discussion, draining, as it does, many thousands of square miles of high mountains where heavy rains and melting snows feed innumerable streams, many of which often grow from innocent rivulets to raging torrents in a few hours' time.

The total area drained is something over 60,000 square miles, and the entire output of all waterways is borne to two trunk streams, the Sacramento and San Joaquin, that merge in Suisun Bay and finally reach the Pacific Ocean through Carquinez Strait, San Pablo and San Francisco Bays.

The table following is taken from Reports on the Control of Floods in the Sacramento Valley and the adjacent San Joaquin Valley, Cal., published in Document No. 81, Sixty-second Congress, first session, and shows the magnitude of the maximum flood discharge of the Sacramento River, as compared with that of several well-known rivers of the United States.

	Drainage area above station (square miles).	Maximum flood dis- charge (cubic feet per second recorded).
Mississippi at Vicksburg.....	1,100,000	1,777,000
Mississippi above Missouri River.....	165,000	366,000
Missouri.....	527,000	546,000
Columbia.....	237,000	1,390,000
Ohio.....	201,700	1,233,000
Arkansas.....	186,300	440,000
Red River.....	90,000	210,000
Sacramento.....	26,000	1 600,000

<sup>1</sup> Estimated, 1907-1909.

The point brought out in the above table is that if the Mississippi had the same discharge per square mile as that of the Sacramento its maximum flood discharge would exceed 25,000,000 cubic feet per second. At this rate it would require only a short period of maximum flood discharge to convert the Mississippi Valley from Vicksburg to St. Louis into an inland sea of considerable depth.

While the great valley of California is one continuous area it is popularly known as two separate valleys—the Sacramento on the north and the San Joaquin on the south. These valleys meet at a point contiguous to the Mokelumne and Cosumnes Rivers, and their drainage, as has been stated, finds a common outlet to the sea.

At one time the Mokelumne River connected with the Sacramento River through Tyler Slough at Walnut Grove and Tyler emptied into the Sacramento at its junction with Georgiana Slough. Tyler Slough now being dammed causes all of the water of the Mokelumne and Cosumnes Rivers to flow into the San Joaquin. Therefore, the dividing line between the drainage area of the Sacramento and San Joaquin Valleys is formed by artificial levees that have been thrown up by reclamation districts.

River and flood conditions in the two valleys being somewhat dissimilar, they will be separately discussed in this paper.

### THE SACRAMENTO VALLEY.

The Sacramento drainage basin extends from Mount Shasta southward to Suisun Bay and from the Trinity Mountains and the Coast Range eastward to the Sierra Nevada. The floor of the Sacramento Valley may be said to begin at about Redding, where its width is only a few miles, and to extend southward for a distance of about 150 miles. Above Redding the valley narrows rapidly and becomes a canyon. It widens as the city of Sacramento is approached, being somewhat over 50 miles at its widest point. The level part of the valley comprises an area of some 4,600 square miles. That part included between the summits of the abutting

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mountains comprises about 19,000 square miles, or nearly 13,000,000 acres.

The eastern watershed of the Sacramento Valley ranges in elevation from 10,000 feet in the south to 6,000 or 7,000 feet in the north. The western watershed ranges from 4,000 feet in the south to 9,000 feet in the north, and the northern watershed from 4,000 to 8,000 feet, exclusive of Mount Shasta, which has an elevation of 14,380 feet. (Water-Supply Paper No. 251, U. S. Geological Survey.)

The mean annual precipitation in the Sacramento watershed increases with altitude and is greatest at about 5,000 feet. Beyond this elevation it decreases. It increases as the upper end of the valley is approached, being about 18 inches at Rio Vista, 20 inches at Sacramento city, 23 inches at Chico, 25 inches at Red Bluff, and 36 inches at Redding. There is a noticeable increase in the mean annual precipitation as the foothill sections are approached and a marked increase thence through the hills and up the flanks of the Sierras. (See figs. 2 and 3.)

In figure 2 the shaded columns indicate the annual precipitation in inches for the following points, viz:

Station.	Eleva- tion.	Station.	Eleva- tion.
	<i>Feet.</i>		<i>Feet.</i>
No. 1. Sacramento.....	71	No. 10. Auburn.....	1,360
No. 2. Palermo.....	213	No. 11. Dunsmuir.....	2,285
No. 3. Red Bluff.....	307	No. 12. Colfax.....	2,421
No. 4. Redding.....	552	No. 13. Nevada City.....	2,540
No. 5. Fruto.....	624	No. 14. Grass Valley.....	2,690
No. 6. Newcastle.....	970	No. 15. Edgewood.....	2,955
No. 7. Shasta.....	1,049	No. 16. Sisson.....	3,555
No. 8. Delta.....	1,138	No. 17. Bowmans Dam.....	5,500
No. 9. Upper Lake.....	1,350	No. 18. Summit.....	7,017

In 1909, 113.85 inches of precipitation occurred at Bowmans Dam and 114.85 inches at Delta. At Magalia, in Butte County, there were 150.62 inches in the same year.

In the diagram on page 14 the figures at the top of columns have the following significance:

- 1 equals season 1906-7.  
2 equals season 1907-8.  
3 equals season 1908-9.
- 4 equals season 1909-10.  
5 equals season 1910-11.  
6 equals season 1911-12.

The year is divided into two fairly well-defined seasons—the dry and the wet. The dry season extends from May to October, inclusive, and the wet from November to April, inclusive. More than 75 per cent of the annual precipitation occurs during the four months ending with March. The precipitation that occurs in the floor of the valley, that is, south of Redding, is invariably in the form of rain. Above the 4,000-foot level it is mostly in the form of snow, although heavy snow sometimes falls at altitudes as low as 2,000 feet.

**FLOODS OF SACRAMENTO AND SAN JOAQUIN WATERSHEDS. 13**

(In inches.)

**FIG. 2.—Normal annual precipitation at 18 stations in the Sacramento watershed.**

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In the report of the commissioner of public works in 1894 the total area of the Sacramento Valley is given as 4,250 square miles, 2,510 of which are described as highlands—that is, not subject to overflow; 450 square miles of lowlands overflowed occasionally by high floods; and 1,250 square miles of lowlands overflowed periodically. The above figures are, of course, now subject to revision on account of the fact that many of the lowlands included in the report have been reclaimed, much of which are now practically immune from even the highest floods.

FIG. 3.—Seasonal precipitation at three stations in the central valleys for six seasons.  
(In inches.)

### THE SACRAMENTO RIVER.

The Sacramento River rises on the southwestern slopes of Mount Shasta and flows almost due south for a distance of about 370 miles, and discharges into Suisun Bay. It is navigable as far as Red Bluff, 265 miles from its mouth. It emerges from its rocky canyons a short distance above Redding, but is mostly confined within banks of sufficient height to carry its maximum flood discharge until a point a short distance below Red Bluff is reached; thence it flows through a practically level plain.

The lower course of the river for a distance of nearly 100 miles occupies a ridge from 5 to 20 feet higher than the troughs of the nearly parallel flood basins on each side, which are from 2 to 7 miles from the river.

### RIVER STATIONS ON THE SACRAMENTO.

The river service on the Sacramento River now embraces seven regular river and rainfall stations, where gage readings are taken

daily the year round. During the seven months ending with May, river stages and 24-hour precipitation are telegraphed daily at 7 a. m., and oftener, should floods be imminent, or in progress, to the river center at Sacramento. In addition to the stations named, special stations are maintained at Dunsmuir and Sisson, from which reports of heavy rains are wired.

The following are the regular river and rainfall stations named, from north to south: Kennett, Red Bluff, Jacinto, Colusa, Knights Landing, Sacramento, and Rio Vista. The numerical values of highest, lowest, and mean stages of the rivers for each month and the year follow in a series of tables, and the same values are presented graphically in figures 4 to 14, inclusive.

Mean monthly river stages, Sacramento system.

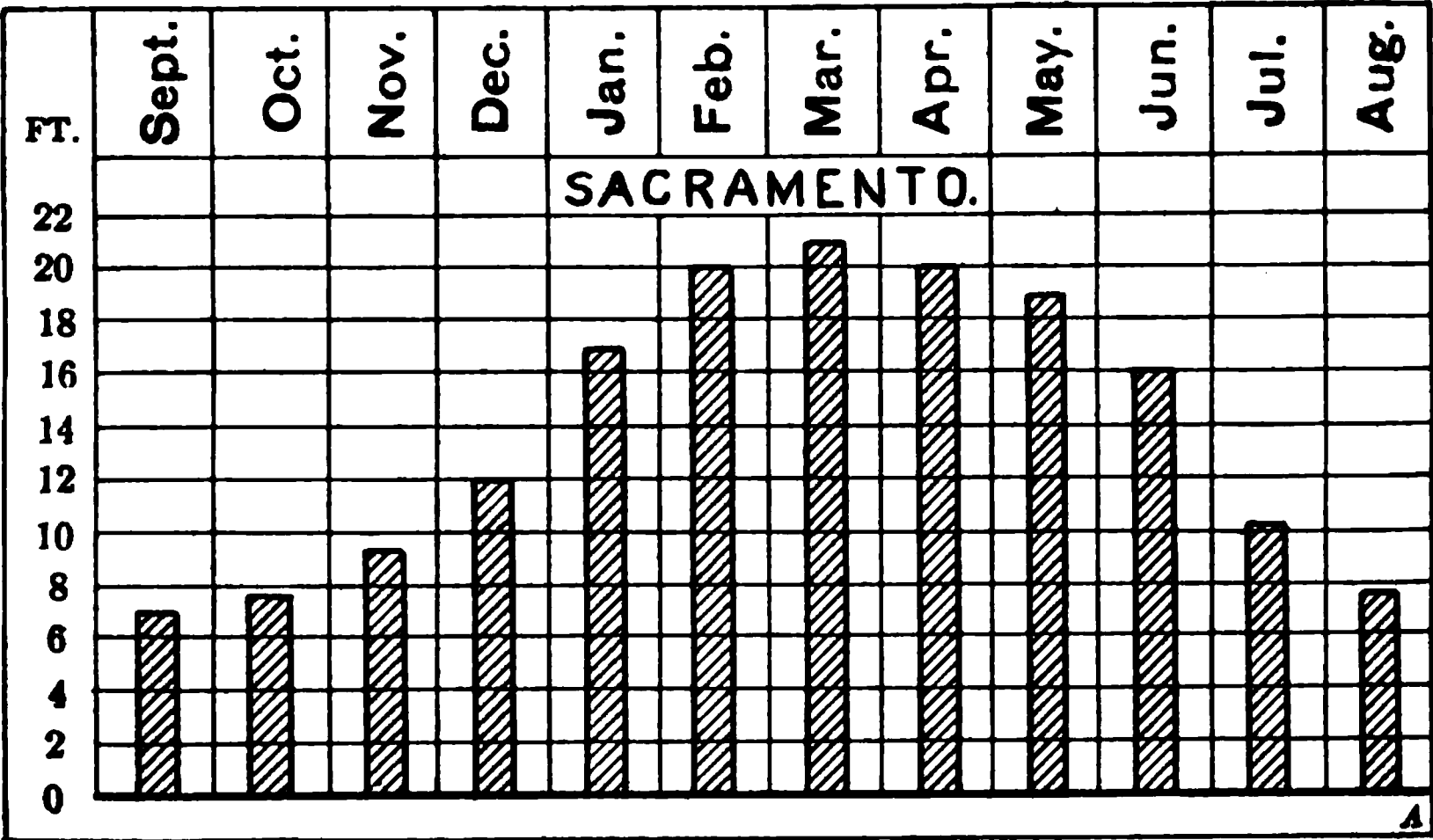


FIG. 4. — Mean monthly river stages.

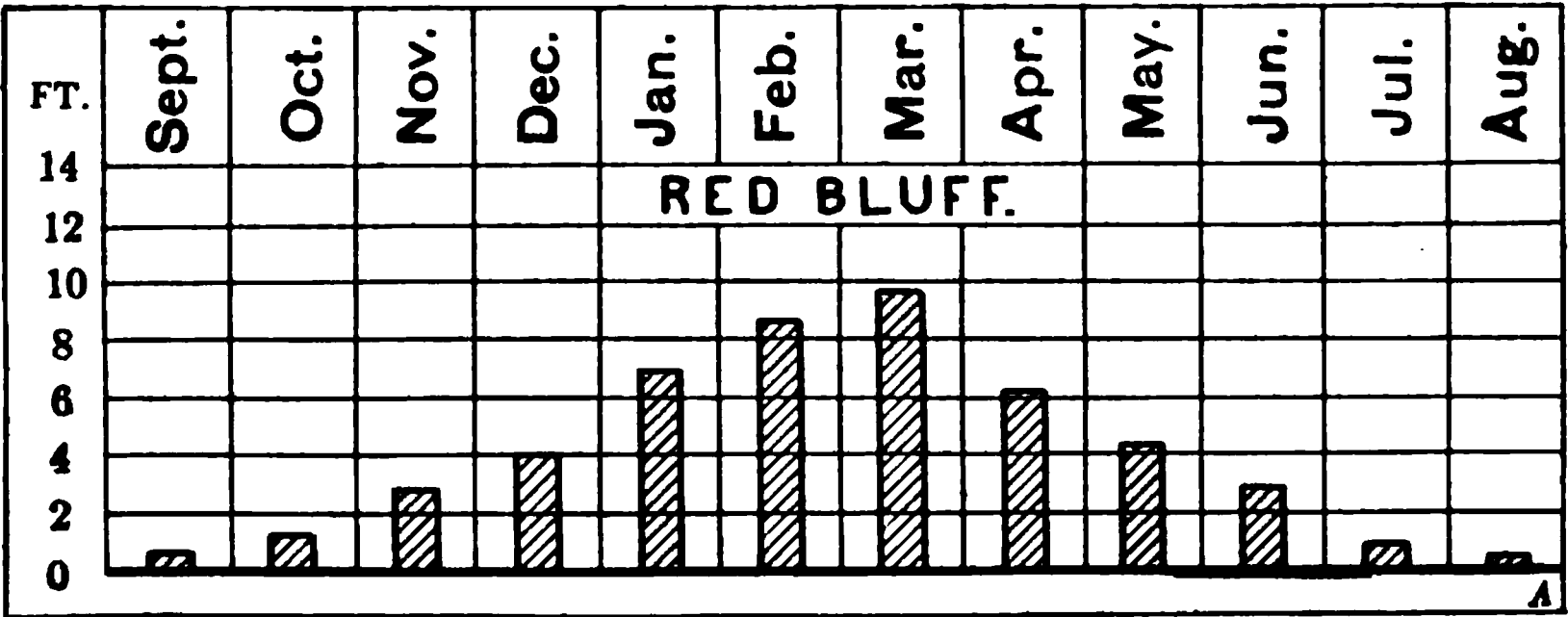


FIG. 4a. — Mean monthly river stages.

Mean monthly river stages, Sacramento system—Continued.

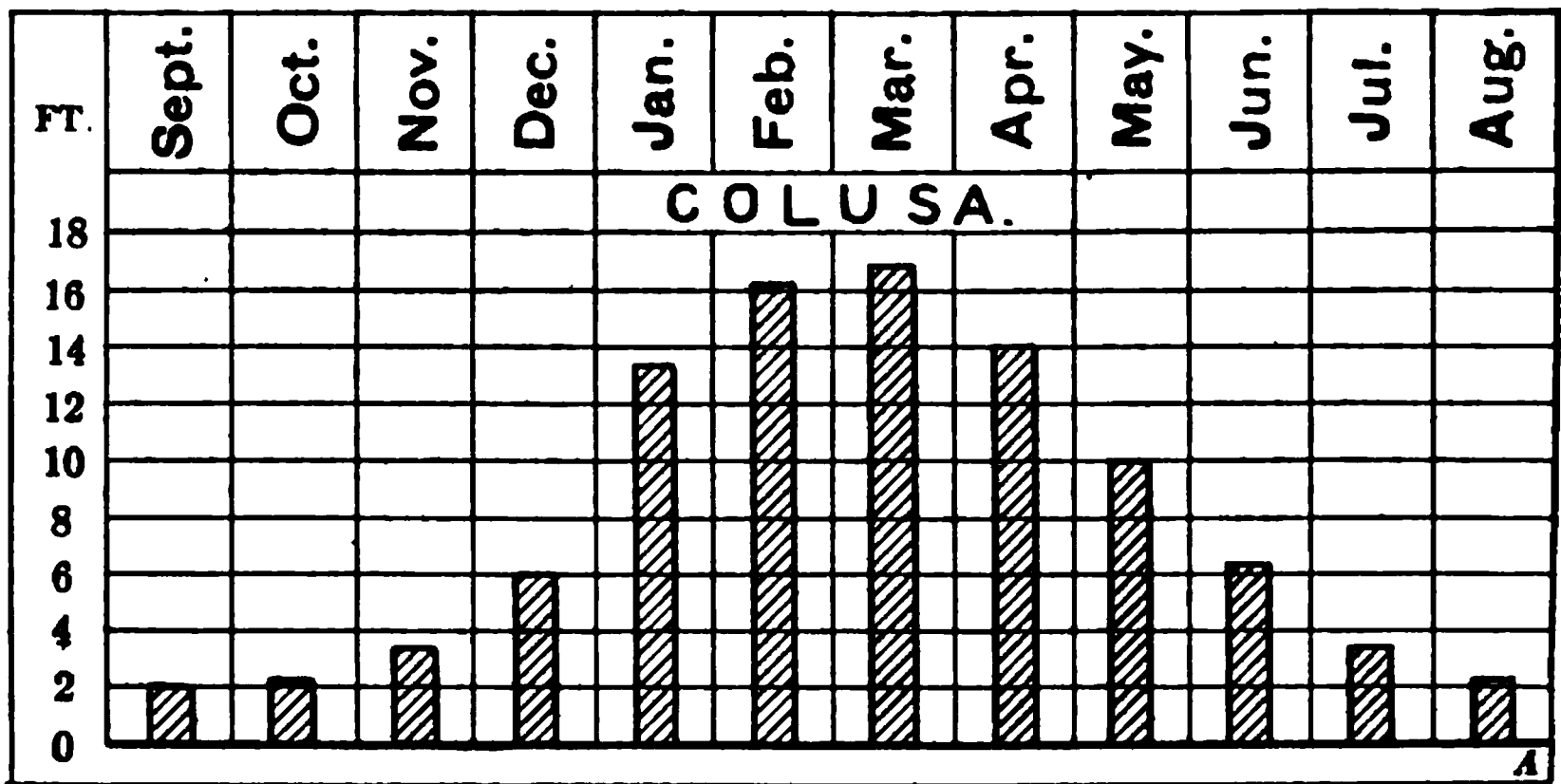


FIG. 4b.—Mean monthly river stages.

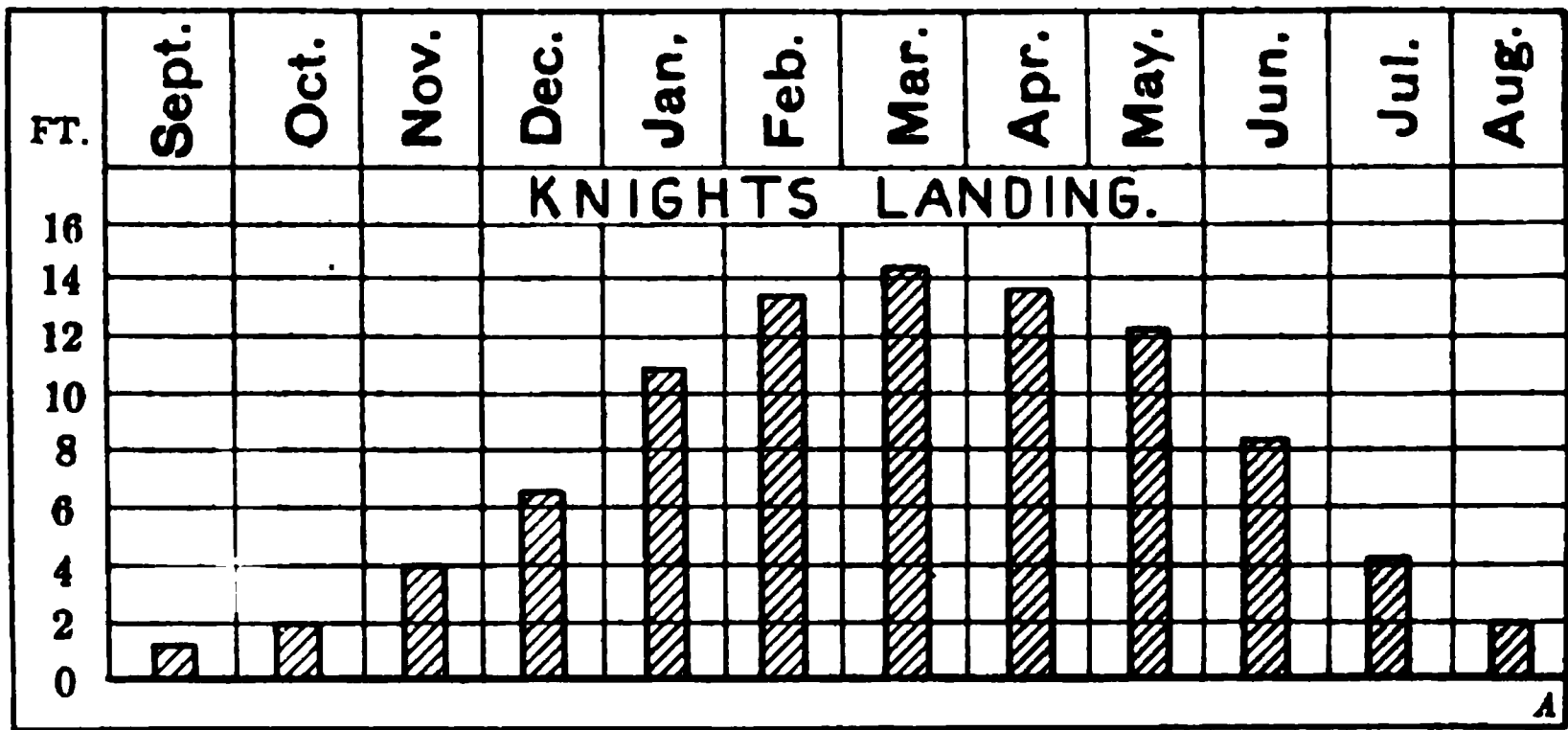


FIG. 4c.—Mean monthly river stages.



Mean monthly river stages, Sacramento system, Sacramento, Cal.—Continued.

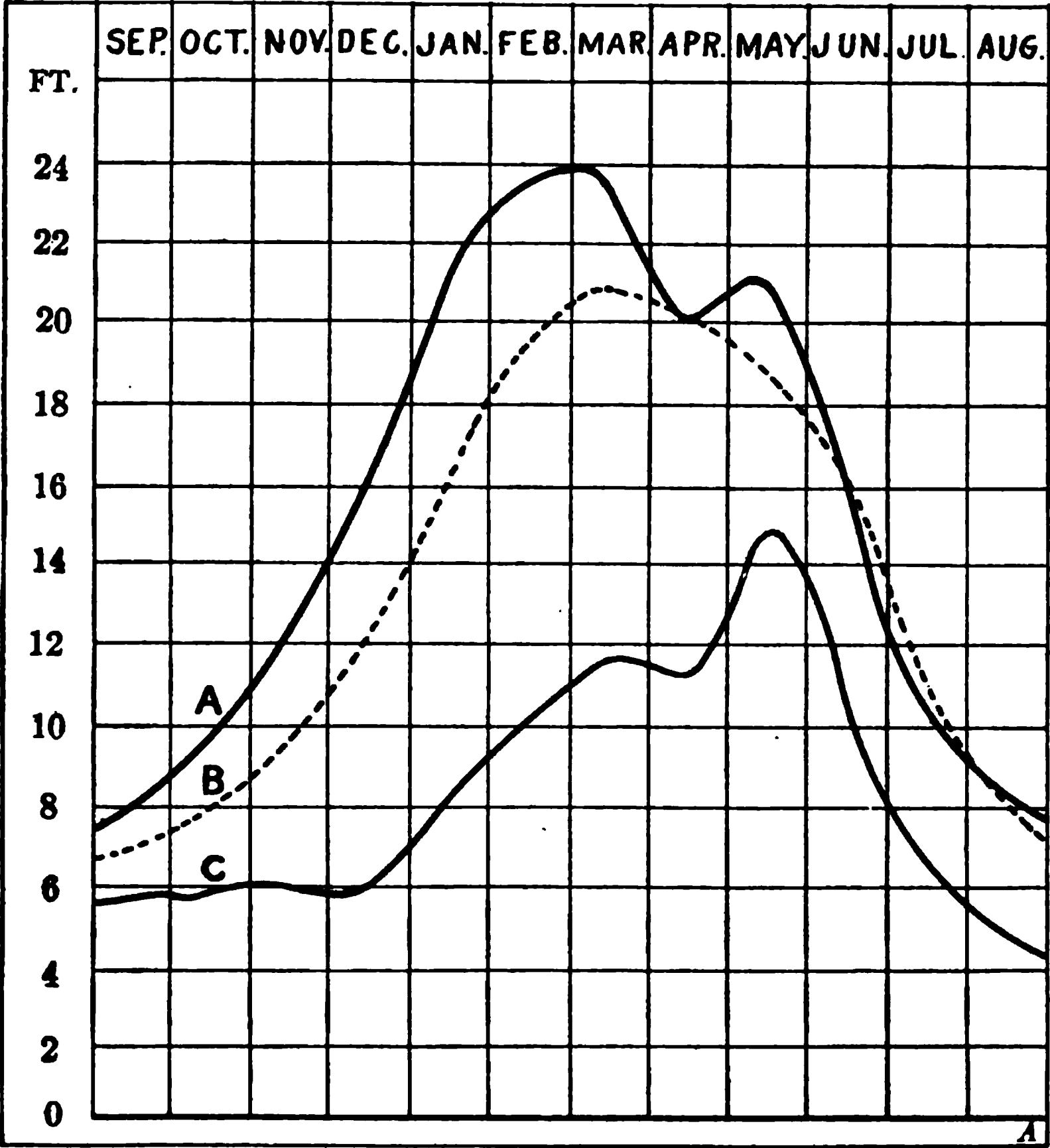


FIG. 5.—Mean monthly river stages. A, season 1900-1901 high water; B, mean stage 12 years; C, low-water season, 1911-12.

*Highest, lowest, and mean seasonal stages, Sacramento River system.*

(In feet.)

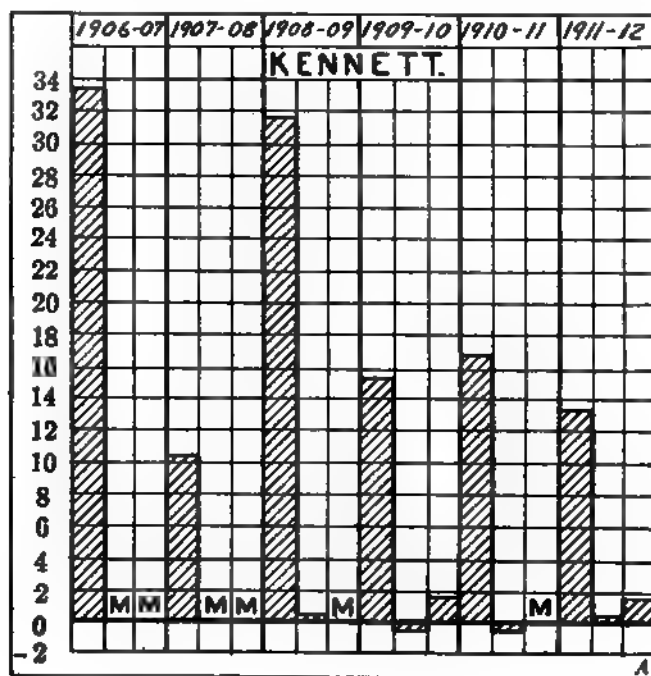


FIG. 6.—Highest, lowest, and mean stages.

FIG. 7.—Highest, lowest, and mean stages. M = Missing

*Highest, lowest, and mean seasonal stages, Sacramento River system--Continued.*  
(In feet )

FIG. 8.—Highest, lowest, and mean stages.

FIG. 9.—Highest, lowest, and mean stages.

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*Highest, lowest, and mean seasonal stages, Sacramento River system*  
(In feet.)

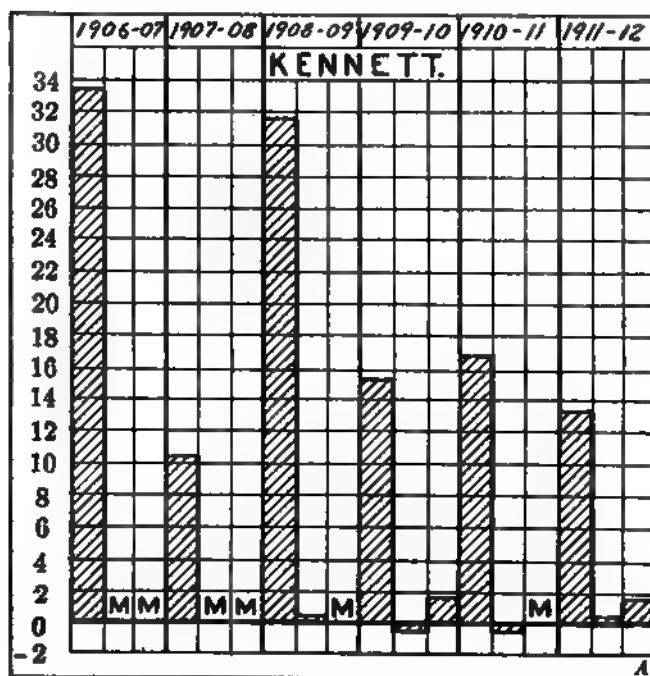


FIG. 6.—Highest, lowest, and mean stages.

FIG. 7.—Highest, lowest, and mean stages. M = Missing

*Highest, lowest, and mean seasonal stages, Sacramento River system—Continued.*

(In feet.)

FIG. 8.—Highest, lowest, and mean stages.

FIG. 9.—Highest, lowest, and mean stages.

*Highest, lowest, and mean seasonal stages, Sacramento River system—Continued.*

(In feet.)

FIG. 10.—Highest, lowest, and mean stages.

FIG. 10a.—Highest, lowest, and mean stages.

*Highest, lowest, and mean seasonal stages, Sacramento River system—Continued.*

(In feet.)

FIG. 11.—Highest, lowest, and mean stages.

FIG. 11a.—Highest, lowest, and mean stages.



Highest, lowest, and mean seasonal stages, Sacramento River system – Continued.  
(In feet.)

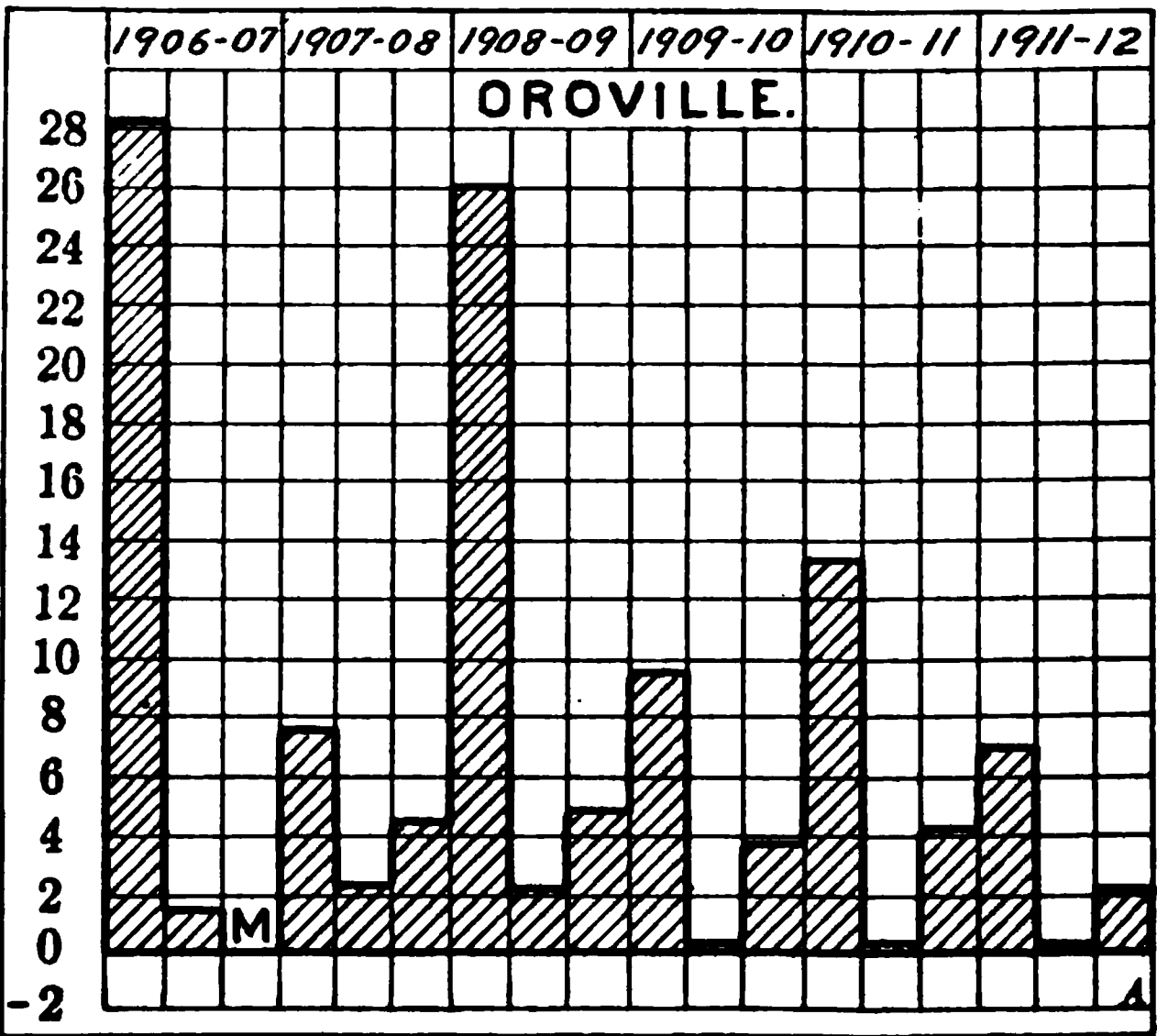


FIG. 12.—Highest, lowest, and mean stages.

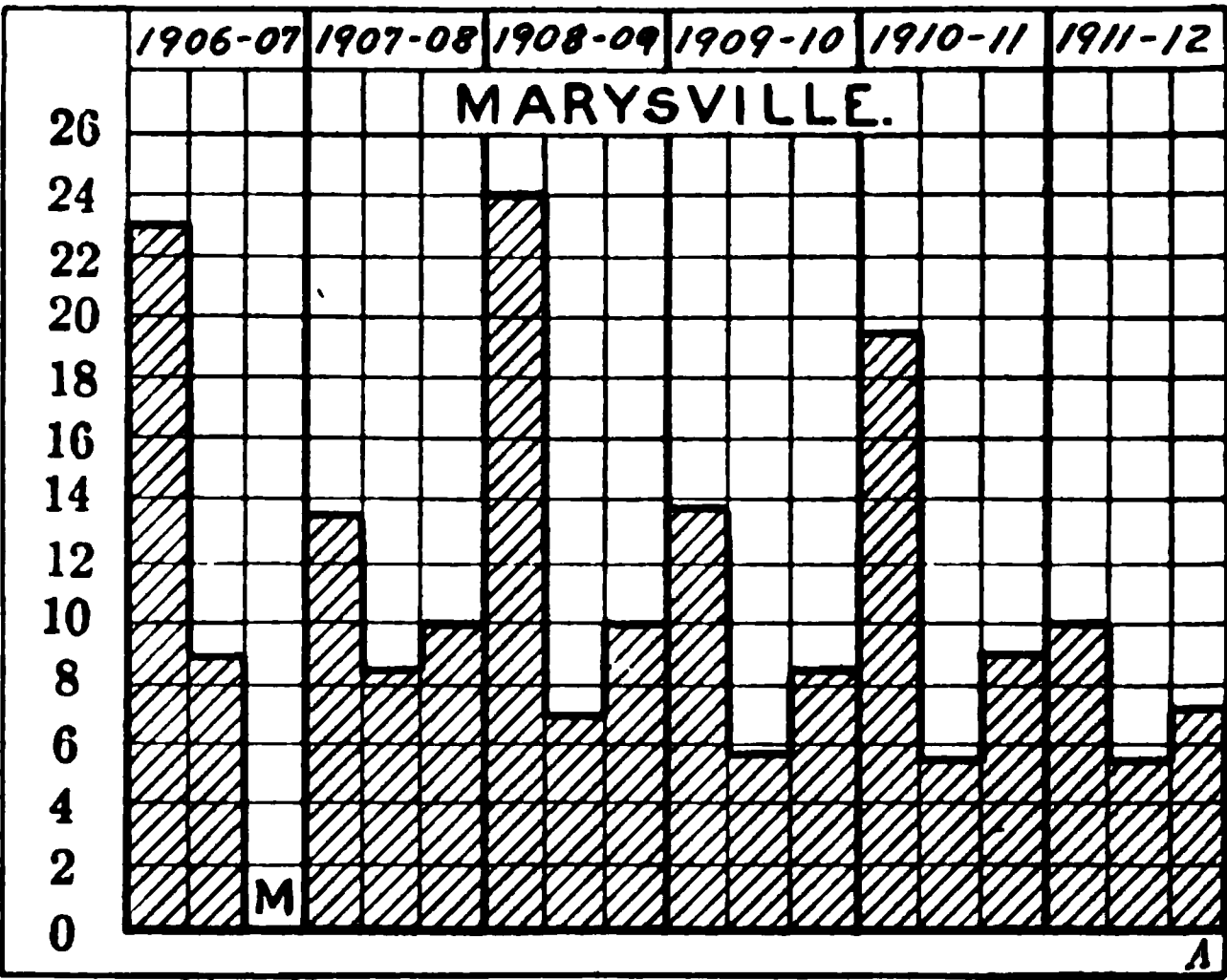


FIG. 13. —Highest, lowest, and mean stages.

*Highest, lowest, and mean seasonal stages, Sacramento River system—Continued*

(Highest only for Marysville, 1862-1906.)

(In feet.)

FIG. 13b.—Highest stages.

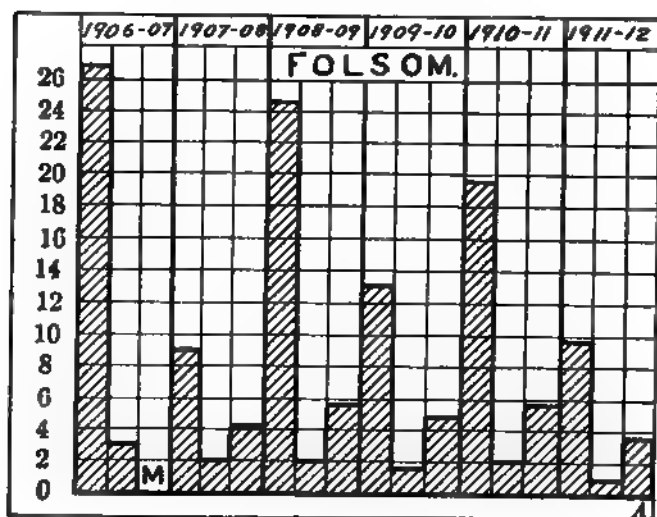


FIG. 14.—Highest, lowest, and mean stages.



TABLE NO. 2.—Highest, lowest, and mean stages for each month and the mean for each year at Red Bluff.

Stages in bold-face type indicate the extremes for each year.  
Red Bluff is on the Sacramento River, 265 miles from its mouth. Elevation, 236 feet; flood stage, 23 feet.

Year.	September.			October.			November.			December.			January.			February.		
	High.		Low.	High.		Low.	High.		Low.	High.		Low.	High.		Low.	High.		Low.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1899-1900.....																		
1900-1.....	1.3	-0.5	-0.3	8.0	-0.5	1.5	7.3	0.4	2.4	17.6	3.1	6.8	24.7	2.7	9.4	7.7	1.8	3.4
1901-2.....	0.4	- .4	- .2	2.0	- .1	.3	12.3	-	2.0	17.5	1.1	4.2	19.4	4.3	8.1	20.1	4.3	8.9
1902-3.....	.2	- .1	.1	4.0	- .1	.8	23.3	.5	5.9	12.4	2.5	5.8	6.7	.6	1.9	24.7	.6	15.1
1903-4.....	.0	- .2	- .1	1.2	-	.2	24.5	.0	7.5	14.4	2.9	5.4	24.4	1.8	6.8	6.2	4.2	4.8
1904-5.....	5.7	.3	.9	17.4	.4	4.2	5.4	1.8	3.2	16.0	3.4	5.8	5.0	2.8	3.6	28.2	3.4	12.0
1905-6.....	.3	.2	.3	.3	.2	.3	1.3	.3	.5	1.3	.6	.7	24.5	2.5	9.3	19.3	4.6	8.4
1906-7.....	.7	.4	.6	.5	.3	.4	3.5	.3	.8	17.5	.6	4.2	24.6	.7	5.0	13.0	2.7	6.9
1907-8.....	1.2	.9	1.1	1.8	.9	1.1	1.7	.9	1.1	12.0	1.0	3.3	15.0	3.8	6.8	24.4	6.3	11.9
1908-9.....	.8	.5	.6	3.0	.6	1.0	3.0	.8	1.4	3.9	1.0	3.3	16.5	3.0	7.1	22.0	3.9	7.7
1909-10.....	1.8	1.0	1.1	2.4	1.3	1.5	12.7	1.6	3.9	22.4	2.8	5.1	27.9	1.8	16.4	30.1	9.4	15.8
1910-11.....	1.1	1.0	1.0	1.8	1.0	1.1	5.8	1.0	1.7	7.0	1.8	3.4	13.8	2.9	5.5	21.5	4.0	6.7
1911-12.....	1.4	1.2	1.2	1.4	1.3	1.3	1.4	1.3	1.4	1.6	1.4	1.4	18.5	1.6	5.3	15.5	3.7	8.0
1899-1912.....	5.7	- .5	.5	17.4	- .5	1.1	24.5	- .1	2.6	22.4	.6	4.0	27.9	.6	6.8	30.1	.6	8.7

Year.	March.			April.			May.			June.			July.			August.			An-nual.
	High.		Low.	High.		Low.	High.		Low.	High.		Low.	High.		Low.	High.		Low.	
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1899-1900.....	23.2	2.9	6.3	3.3	3.2	3.8	1.4	2.5	1.2	-0.3	0.3	-0.3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	3.6
1900-1.....	12.4	4.2	7.4	6.6	6.5	6.5	2.2	3.1	2.0	.6	1.2	.5	-	-	-	.1	.2	.2	3.7
1901-2.....	16.6	4.7	9.3	6.4	4.4	4.9	3.6	4.0	3.6	1.5	2.3	1.4	.3	.2	.3	.2	.3	.3	3.6
1902-3.....	19.8	5.2	9.2	4.1	4.1	6.0	1.8	3.0	1.6	.4	.8	.4	.2	.2	.0	.1	.4	.1	5.9
1903-4.....	26.3	10.4	17.8	8.6	8.6	10.2	5.5	7.5	5.5	3.8	4.7	3.1	.5	.3	.3	.5	.3	.4	4.6
1904-5.....	20.0	5.0	9.6	15.4	10.6	14.8	3.0	6.2	3.0	1.5	2.4	1.5	.4	.1	.1	.4	.3	.1	4.1
1905-6.....	25.5	6.4	11.9	25.5	25.5	14.0	4.0	5.1	6.0	3.0	5.9	3.0	1.4	1.4	2.2	1.4	1.2	1.2	5.1
1906-7.....	26.8	7.7	13.8	6.5	6.5	10.1	4.0	3.6	3.0	2.7	3.6	2.7	1.5	1.5	2.1	1.5	1.3	1.3	3.2
1907-8.....	6.7	3.8	5.2	3.3	3.3	3.9	3.0	4.7	4.1	1.9	2.4	1.9	.8	.8	1.4	.8	.7	.7	5.2
1908-9.....	12.8	6.8	8.4	7.8	4.9	6.7	3.8	3.1	3.0	2.4	3.1	2.3	1.5	1.5	1.8	1.5	1.3	1.3	3.8
1909-10.....	16.2	6.5	9.4	7.1	5.9	6.6	2.2	3.1	2.1	1.4	2.0	1.4	1.0	1.0	1.2	1.0	1.0	1.0	4.3
1910-11.....	25.5	3.6	10.2	15.0	4.0	7.3	4.7	5.6	5.0	2.4	3.7	2.4	1.5	1.5	1.9	1.5	1.2	1.2	2.7
1911-12.....	10.8	2.4	5.2	9.1	3.1	4.0	3.8	5.6	5.0	2.0	3.1	2.0	1.2	1.2	1.6	1.2	1.0	1.0	
1899-1912.....	26.8	2.4	9.5	25.5	3.1	6.4	1.4	4.4	10.8	- .3	2.7	3.1	- .5	- .5	1.2	1.5	- .5	.6	4.2



TABLE NO. 4.—Highest, lowest, and mean stages for each month and the mean for each year at Colusa.

Stages in bold-face type indicate the extremes for each year.  
Colusa is on the Sacramento River, 156 miles from its mouth and 57 miles above Sacramento. Elevation, 36.8 feet; flood stage, 29 feet.

Year.	September.			October.			November.			December.			January.			February.		
	High.		Low.	High.		Low.	High.		Low.	High.		Low.	High.		Low.	High.		Low.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1906-7.....			3.5										25.1	7.4	16.4	28.2	16.1	22.1
1907-8.....	3.7	3.3	3.5	4.1	3.3	3.5	4.5	3.6	3.8	21.3	3.7	7.3	21.8	8.9	15.6	25.2	11.1	17.1
1908-9.....	2.4	2.0	2.1	4.3	2.0	2.6	6.7	2.7	3.4	6.2	3.4	4.1	28.0	3.7	22.6	27.4	19.8	22.8
1909-10.....	2.7	2.0	2.1				19.2	3.2	6.8	23.0	6.3	10.6	21.8	6.4	10.6	23.2	9.7	12.8
1910-11.....	1.5	1.0	1.2	2.4	1.2	1.4	6.3	1.4	2.3	11.4	3.2	5.9	23.3	2.6	8.6	24.2	8.7	16.3
1911-12.....	1.8	1.2	1.3	2.0	1.6	1.8	2.2	1.8	1.9	2.3	1.9	2.0	21.2	2.1	5.6	9.8	4.9	6.7
1906-1912.....	3.7	1.0	2.0	4.3	1.2	2.3	19.2	1.4	3.6	23.0	1.9	6.0	28.0	2.1	13.2	28.2	4.9	16.3

Year.	March.			April.			May.			June.			July.			August.			Annual.
	High.		Low.	High.		Low.	High.		Low.	High.		Low.	High.		Low.	High.		Low.	
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1906-7.....	28.6	18.6	22.4	22.0	13.8	19.8	15.4	10.8	12.9	11.8	7.5	9.6	4.8	4.8	3.7	4.1			8.0
1907-8.....	14.8	10.3	12.8	8.7	8.7	12.8	10.6	7.6	8.7	7.3	4.3	5.8	2.6	2.6	2.0	2.3			9.0
1908-9.....	20.9	15.5	17.7	13.5	15.1	15.1	13.3	8.9	10.9	9.2	5.6	7.4	2.9	2.9	2.1	2.4			
1909-10.....	23.0	13.6	18.1	9.3	12.3	12.3	8.9	4.6	6.7	4.5	2.4	3.3	1.4	1.9	1.0	1.1			
1910-11.....	27.4	8.6	19.3	13.2	16.7	16.7	14.1	10.1	12.0	10.6	5.2	8.2	2.6	3.7	1.3	1.9			8.1
1911-12.....	18.3	4.4	9.8	5.6	7.0	7.0	15.9	7.1	10.3	10.3	3.2	5.5	1.2	1.9	.7	.9			4.6
1906-1912.....	28.6	4.4	16.7	5.6	14.0	14.0	15.9	4.6	10.2	11.8	2.4	6.6	1.2	3.4	.7	2.1			7.6

TABLE NO. 5.—Highest, lowest, and mean stages for each month and the mean for each year at Knights Landing.

Stages in bold-face type indicate the extremes for each year.  
Knights Landing is on the Sacramento River, 99 miles from its mouth and 35 miles above Sacramento. Elevation, 16.1 feet; flood stage, 18 feet.

Year.	September.			October.			November.			December.			January.			February.		
	High.		Low.	High.		Low.	High.		Low.	High.		Low.	High.		Low.	High.		Low.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1899-1900.....	1.3	0.4	0.7	6.8	0.4	2.9	10.4	2.2	5.1	13.2	5.5	9.0	17.2	12.2	14.9	11.9	7.8	9.8
1900-1901.....	1.6	.3	.6	2.7	.5	1.0	10.4	1.2	2.7	11.8	4.7	8.2	15.2	9.0	13.9	17.9	12.3	14.1
1901-2.....	1.3	.6	.9	5.0	.5	1.4	13.4	1.8	8.7	13.7	6.8	11.0	5.2	3.5	4.2	19.2	3.4	12.7
1902-3.....	.9	.7	.7	2.5	.7	1.2	16.2	1.0	8.0	15.2	7.5	11.3	17.7	6.5	10.8	16.7	12.1	14.4
1903-4.....	6.3	2.8	3.6	9.9	3.4	6.1	7.7	5.2	5.8	12.9	5.4	4.2	17.8	7.2	8.6	19.1	6.7	12.7
1904-5.....	2.6	2.2	2.3	2.3	2.2	2.2	3.0	2.3	2.5	3.9	2.8	3.1	17.7	3.0	15.6	17.6	15.2	16.3
1905-6.....	4.6	3.5	3.9	3.5	2.9	3.0	6.3	3.0	3.9	16.3	3.3	8.4	16.5	13.5	10.7	17.2	11.2	14.2
1906-7.....	3.3	2.4	2.8	2.8	2.0	2.2	3.4	2.5	2.7	12.5	2.6	5.9	15.0	8.6	12.3	18.8	14.9	16.3
1907-8.....	.6	.2	.4	3.0	.2	1.1	5.4	1.2	2.0	5.0	2.1	2.9	19.1	2.5	15.4	18.8	17.6	18.0
1908-9.....	1.2	.4	.8	2.4	1.0	1.5	13.3	2.1	5.5	15.1	7.2	11.5	14.2	7.7	10.7	14.7	10.6	12.4
1909-10.....	.5	.4	.1	1.0	.0	.3	5.8	.2	1.2	10.7	2.5	5.3	16.2	1.7	7.4	17.2	10.4	15.0
1910-11.....	.5	.1	.2	.8	.4	.6	1.4	.5	.8	1.1	.6	.8	12.0	.7	3.6	9.3	4.1	5.9
1911-12.....	6.3	— .4	1.4	9.9	.0	2.0	16.2	.2	4.1	16.3	.6	6.8	19.1	.7	11.0	19.2	3.4	13.5
1899-1912.....																		

Year.	March.			April.			May.			June.			July.			August.			An-nual.
	High.		Low.	High.		Low.	High.		Low.	High.		Low.	High.		Low.	High.		Low.	
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1899-1900.....	16.0	12.5	13.5	12.2	9.8	11.3	10.8	7.5	9.7	7.4	3.3	5.3	3.2	1.0	0.5	1.0	0.7	.....	7.7
1900-1901.....	17.2	12.2	14.5	11.9	10.0	10.6	12.2	10.2	11.6	10.0	4.0	6.6	3.8	1.2	.5	1.7	.8	.....	7.1
1901-2.....	18.4	12.0	14.7	14.7	11.2	13.4	13.8	11.8	12.8	11.9	5.8	9.0	5.8	2.9	1.4	3.1	2.2	.....	8.2
1902-3.....	16.4	12.4	14.4	16.9	13.0	15.0	12.9	8.8	11.2	8.8	3.8	6.3	3.8	1.7	.9	1.6	1.1	.....	9.4
1903-4.....	19.0	16.7	17.4	17.2	15.8	16.3	15.8	14.4	15.4	14.2	7.9	11.3	7.8	4.2	3.9	5.2	4.2	.....	9.5
1904-5.....	17.4	13.4	15.7	17.2	13.8	15.4	14.3	12.0	13.1	11.9	7.0	9.7	6.8	3.9	2.6	3.9	3.2	.....	.....
1905-6.....	20.2	15.6	16.6	18.9	15.9	16.8	16.7	13.7	15.4	16.8	13.3	15.6	13.0	6.3	4.7	8.2	6.3	.....	.....
1906-7.....	12.6	10.7	11.9	17.2	15.2	16.7	15.7	13.7	14.8	13.6	10.8	12.6	10.6	6.0	3.4	6.0	4.5	.....	10.4
1907-8.....	17.5	15.4	16.5	11.2	8.8	10.1	10.5	8.6	9.4	8.4	3.9	6.2	3.9	1.4	.5	1.3	.8	.....	6.7
1908-9.....	16.1	14.3	15.3	15.6	14.3	14.8	14.2	11.6	13.1	11.5	7.6	9.9	7.5	3.3	1.2	3.2	2.1	.....	8.4
1909-10.....	17.5	15.3	16.5	15.3	12.2	15.7	11.8	5.4	8.7	5.3	2.2	3.4	2.1	.5	.3	.4	.0	.....	7.2
1910-11.....	17.5	10.0	15.3	16.5	14.5	15.6	14.9	13.2	14.1	13.4	9.0	12.0	8.4	2.2	.4	2.1	1.0	.....	7.6
1911-12.....	11.1	3.6	8.1	9.7	5.1	6.3	11.4	6.8	9.5	10.8	2.6	5.8	2.4	— .3	— 1.2	— .4	— .8	.....	3.5
1899-1912.....	20.2	3.6	14.5	18.9	5.1	13.7	16.7	6.8	12.2	16.8	2.2	8.7	13.0	— .3	— 1.2	8.2	2.1	.....	7.8



**TABLE No. 6.**—*Highest, lowest, and mean stages for each month and the mean for each year at Sacramento.*

**Stages in bold-face type indicate the extremes for each year.**

Sacramento is on the Sacramento River, 64 miles above Suisun Bay and 38 miles above Rio Vista. Elevation, -0.5 foot; flood stage, 29 feet.

Year.	September.			October.			November.			December.			January.			February.		
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1889-1900.....																		
1900-1.....	7.9	7.6	7.8	13.5	7.6	9.5	19.5	8.8	12.0	19.5	12.0	15.2	27.0	21.7	24.4	21.4	15.5	17.9
1901-2.....	8.5	7.2	7.6	10.7	7.5	8.2	14.6	8.1	9.4	20.5	11.6	15.4	22.7	16.0	21.5	28.2	21.0	23.5
1902-3.....	7.9	7.2	7.5	10.3	6.9	7.7	16.9	8.1	13.1	18.1	12.6	15.9	23.2	9.8	10.8	27.6	9.8	18.8
1903-4.....	7.3	7.0	7.1	8.7	7.0	7.5	20.5	7.3	14.1	19.6	14.3	17.1	15.8	12.6	16.5	23.2	18.7	21.1
1904-5.....	12.0	8.2	9.1	18.0	9.2	11.7	12.0	10.4	11.0	17.0	10.6	11.7	20.8	13.3	14.4	27.9	12.8	19.2
1905-6.....	7.0	6.3	6.6	6.7	6.4	6.5	7.4	6.5	6.7	7.8	6.9	7.1	23.0	16.6	18.7	22.0	19.8	20.9
1906-7.....	8.8	7.6	8.0	7.6	6.8	7.1	10.3	7.0	8.0	20.5	7.3	12.5	20.6	7.0	15.2	21.5	16.1	18.7
1907-8.....	8.5	7.5	8.0	8.0	7.3	7.5	8.4	7.5	7.8	15.3	7.7	10.3	19.3	18.2	19.4	27.2	20.5	23.3
1908-9.....	5.6	5.3	5.5	8.3	5.3	5.9	9.3	5.8	6.6	9.6	6.8	7.5	29.6	13.2	15.9	20.4	16.4	18.9
1909-10.....	6.4	5.5	5.9	7.0	6.0	6.4	18.7	6.7	10.8	22.0	13.1	17.3	20.0	7.2	21.6	24.0	21.1	22.6
1910-11.....	6.3	5.1	5.5	6.2	5.3	5.7	9.4	5.7	6.5	14.0	7.4	9.5	26.4	14.0	16.8	18.9	15.7	17.4
1911-12.....	5.9	5.5	5.7	6.0	5.6	5.8	6.7	5.7	6.0	6.2	5.7	5.9	13.9	5.8	8.1	11.2	8.6	9.8
1889-1912.....	12.0	5.1	7.0	18.0	5.3	7.5	20.5	5.7	9.3	22.0	5.7	12.1	29.6	5.8	16.7	28.2	8.6	19.8

[illegible]



TABLE No. 8.—Highest, lowest, and mean stages for each month and the mean for each year at Marysville.

Stages in bold-face type indicate the extremes for each year.  
Marysville is on the Yuba River at its junction with the Feather River, 44 miles above Sacramento. Elevation, 46.8 feet; flood stage, 28 feet.

Year.	September.			October.			November.			December.			January.			February.			
	High.		Mean.	High.		Low.	Mean.	High.		Low.	Mean.	High.		Low.	Mean.	High.		Low.	Mean.
	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.		
1906-7.....	9.1	8.9	9.0	8.7	8.8	9.0	8.5	8.6	13.1	8.5	9.6	14.7	10.8	11.7	21.9	12.7	14.5		
1907-8.....	8.5	8.3	8.4	8.3	8.6	9.7	8.5	8.7	10.2	8.6	8.9	13.4	9.4	10.7	12.7	9.8	10.5		
1908-9.....	6.7	6.3	6.5	6.2	6.6	14.0	6.9	8.8	14.9	8.0	9.6	12.4	8.7	9.6	10.9	8.8	12.3		
1909-10.....	7.1	5.8	6.0	5.7	5.6	7.4	5.8	6.2	9.4	6.2	6.9	19.3	6.1	9.4	18.2	8.3	10.0		
1910-11.....	7.5	7.3	7.3	6.7	7.1	8.2	6.3	6.8	6.5	6.1	6.3	9.3	6.3	7.2	7.8	6.7	7.1		
1911-12.....																			
1906-1912.....	9.1	5.8	7.4	5.7	7.3	14.0	5.8	7.8	14.9	6.1	8.3	24.0	6.1	10.6	21.9	6.7	10.6		

Year.	March.			April.			May.			June.			July.			August.			An-nual.	
	High.		Mean.	High.		Low.	Mean.	High.		Low.	Mean.	High.		Low.	Mean.	High.		Low.		Mean.
	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.			
1906-7.....	23.3	12.7	14.6	15.7	13.6	14.2	13.1	13.6	14.0	11.8	12.7	11.9	9.9	10.8	9.8	9.2	9.3	.....		
1907-8.....	11.6	10.3	10.9	12.5	11.4	12.9	11.0	11.8	11.3	9.7	10.6	9.7	8.8	9.2	8.8	8.5	8.6	10.0		
1908-9.....	11.9	9.9	10.7	12.0	11.0	12.3	10.3	11.3	11.7	9.3	10.4	9.2	7.1	7.9	7.1	6.7	6.8	10.0		
1909-10.....	13.9	10.3	11.2	11.5	10.7	10.7	8.8	9.7	8.9	7.0	7.7	6.9	6.2	6.5	6.2	5.3	6.0	8.6		
1910-11.....	15.5	8.4	10.6	16.0	12.4	12.7	11.3	12.0	13.1	10.5	11.8	10.3	8.1	9.2	8.0	7.4	7.7	9.0		
1911-12.....	9.8	6.7	7.9	9.5	7.2	10.0	8.8	9.5	10.1	6.9	8.4	6.8	5.8	6.1	5.8	5.5	5.6	7.3		
1906-1912.....	23.3	6.7	11.0	16.0	11.4	14.2	8.8	11.3	14.0	6.9	10.3	11.9	5.8	8.3	9.8	5.5	7.3	9.0		

TABLE NO. 7.—Highest, lowest, and mean stages for each month and the mean for each year at Oroville.

Stages in bold-face type indicate the extremes for each year.  
Oroville is on the Feather River, 32 miles above its junction with the Yuba at Marysville, and 76 miles above Sacramento. Elevation, 147.4 feet; flood stage, 25 feet.

Year.	September.			October.			November.			December.			January.			February.		
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1906-7.....	3.8	3.6	3.7	3.7	3.5	3.6	3.7	3.5	3.6	7.8	4.6	7.7	1.4	3.1	6.3	17.6	8.9	
1907-8.....	2.5	2.3	2.3	5.0	2.3	2.6	4.3	2.4	2.8	5.0	3.1	7.7	4.3	5.6	4.4	6.7	5.0	
1908-9.....	2.2	1.0	1.4	3.6	1.0	1.7	9.7	2.0	3.9	11.0	5.4	26.0	2.8	11.0	7.1	9.9	8.0	
1909-10.....	1.4	.5	.9	1.3	.5	.9	5.4	.7	1.5	6.7	2.9	13.3	3.9	4.9	4.6	8.2	5.2	
1910-11.....	1.5	.9	1.0	1.5	.8	1.1	2.3	.7	1.4	1.5	1.2	7.1	1.5	4.1	4.0	9.6	5.6	
1911-12.....													1.3	2.7	2.0	3.2	2.5	
1906-1912.....	3.8	.5	1.9	5.0	.5	2.0	9.7	.7	2.6	11.0	3.4	26.0	1.3	5.2	2.0	17.6	5.9	

Year.	March.			April.			May.			June.			July.			August.			An-nual.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1906-7.....	28.2	5.1	10.9	12.7	10.1	10.9	8.8	9.4	9.0	6.4	7.7	4.6	4.5	5.2	3.8	4.0	4.0	.....	
1907-8.....	7.0	4.7	5.8	7.4	5.6	6.6	5.7	6.2	5.7	3.9	4.9	2.8	2.8	3.2	2.4	2.5	2.5	4.6	
1908-9.....	9.0	6.4	7.1	8.8	6.5	7.5	6.5	7.2	7.0	4.5	5.9	2.3	2.2	3.1	1.5	1.8	1.8	5.2	
1909-10.....	9.0	6.4	7.4	7.0	5.9	6.6	3.4	4.9	3.2	1.7	2.2	.5	1.0	1.2	.6	.8	.8	3.8	
1910-11.....	10.2	4.1	6.8	12.4	7.0	8.9	7.4	8.0	8.1	5.0	6.8	2.0	2.0	3.3	1.0	1.5	1.5	4.3	
1911-12.....	6.1	1.9	3.5	5.1	2.8	3.6	5.0	5.4	5.3	1.4	3.5	.5	.8	.9	.0	.4	.4	2.3	
1906-1912.....	28.2	1.9	6.9	12.7	2.8	7.4	3.4	6.8	9.0	1.4	5.2	.5	4.5	2.8	.0	1.8	1.8	4.0	

TABLE NO. 8.—Highest, lowest, and mean stages for each month and the mean for each year at Marysville.

Stages in bold-face type indicate the extremes for each year.  
Marysville is on the Yuba River at its junction with the Feather River, 44 miles above Sacramento. Elevation, 46.8 feet; flood stage, 28 feet.

Year.	September.			October.			November.			December.			January.			February.		
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1906-7.....	9.1	8.9	9.0	8.9	8.7	8.8	9.0	8.5	8.6	13.1	8.5	9.6	14.7	10.8	11.7	21.9	12.7	14.5
1907-8.....	8.5	8.3	8.4	10.3	8.3	8.6	9.7	8.5	8.7	10.2	8.6	8.9	13.4	9.4	10.7	12.7	9.8	10.5
1908-9.....	6.7	6.3	6.5	7.5	6.2	6.6	14.0	6.9	8.8	14.9	8.0	9.6	24.0	8.6	15.1	15.3	11.0	12.3
1909-10.....	7.1	5.8	6.0	6.4	5.7	5.6	7.4	5.8	6.2	9.4	6.2	6.9	12.4	8.7	9.6	10.9	8.8	9.4
1910-11.....	7.5	7.3	7.3	7.5	6.7	7.1	8.2	6.3	6.8	6.5	6.1	6.3	19.3	6.1	9.4	18.2	8.3	10.0
1911-12.....													9.3	6.3	7.2	7.8	6.7	7.1
1906-1912.....	9.1	5.8	7.4	10.3	5.7	7.3	14.0	5.8	7.8	14.9	6.1	8.3	24.0	6.1	10.6	21.9	6.7	10.6

Year.	March.			April.			May.			June.			July.			August.			Annual.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1906-7.....	23.3	12.7	14.6	15.7	13.6	14.6	14.2	13.1	13.6	14.0	11.8	12.7	11.9	9.9	10.8	9.8	9.2	9.3	.....
1907-8.....	11.6	10.3	10.9	12.5	10.4	11.4	12.9	11.0	11.8	11.3	9.7	10.6	9.7	8.8	9.2	8.8	8.5	8.6	10.0
1908-9.....	11.9	9.9	10.7	12.0	10.2	11.0	12.3	10.3	11.3	11.7	9.3	10.4	9.2	7.1	7.9	7.1	6.7	6.8	10.0
1909-10.....	13.9	10.3	11.2	11.5	10.7	11.1	10.7	8.8	9.7	8.9	7.0	7.7	6.9	6.2	6.5	6.2	5.8	6.0	8.6
1910-11.....	15.5	8.4	10.6	16.0	10.9	12.4	12.7	11.3	12.0	13.1	10.5	11.8	10.3	8.1	9.2	8.0	7.4	7.7	9.0
1911-12.....	9.8	6.7	7.9	9.5	7.2	7.8	10.0	8.8	9.5	10.1	6.9	8.4	6.8	5.8	6.1	5.8	5.5	5.6	7.3
1906-1912.....	23.3	6.7	11.0	16.0	7.2	11.4	14.2	8.8	11.3	14.0	6.9	10.3	11.9	5.8	8.3	9.8	5.5	7.3	9.0

TABLE NO. 9.—*Highest, lowest, and mean stages for each month and the mean for each year at Folsom.*

Stages in bold-face type indicate the extremes for each year.  
Folsom is on the American River 24 miles from its mouth and 25 miles from Sacramento on the Sacramento River. Elevation, 110.6 feet.

Year.	September.			October.			November.			December.			January.			February.		
	High.		Low.	High.		Low.	High.		Low.	High.		Low.	High.		Low.	High.		Low.
	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.
1906-7.....	3.1	3.0	3.0	3.2	2.5	2.9	3.1	2.7	2.9	8.0	2.7	3.9	9.8	3.4	4.6	19.9	6.0	8.5
1907-8.....	2.0	1.9	1.9	5.0	1.9	2.5	4.0	2.3	2.7	3.9	2.5	3.0	9.0	3.8	4.7	5.2	3.8	4.3
1908-9.....	2.0	1.7	1.8	3.0	1.8	2.2	15.2	2.8	4.9	15.6	4.0	6.6	24.5	2.7	10.8	13.5	7.0	8.9
1909-10.....	2.7	1.9	2.1	2.9	1.8	2.1	4.0	2.0	2.6	8.0	2.5	3.7	11.5	4.9	6.5	7.5	5.2	6.0
1910-11.....	2.0	1.1	1.1	.8	.8	.8	2.9	1.4	2.3	2.5	2.1	2.3	19.7	2.5	7.8	14.3	5.1	7.4
1911-12.....													5.4	2.4	3.1	3.4	2.7	3.0
1906-1912.....	3.1	.8	2.0	5.0	.8	2.1	15.2	1.4	3.1	15.6	2.1	3.9	24.5	2.4	6.2	19.9	2.7	6.3

Year.	March.			April.			May.			June.			July.			August.			An-nual.
	High.		Low.	High.		Low.	High.		Low.	High.		Low.	High.		Low.	High.		Low.	
	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	
1906-7.....	26.8	5.9	10.8	12.5	9.5	11.0	12.1	8.3	10.0	11.9	7.0	9.2	4.5	6.2	4.5	3.0	3.7	3.7	.....
1907-8.....	6.3	4.2	5.3	7.5	4.8	5.9	6.7	5.1	6.0	5.6	4.1	4.9	2.2	3.2	2.7	1.9	2.2	2.2	4.1
1908-9.....	9.3	5.8	7.0	11.0	5.8	8.3	10.6	6.1	8.5	11.5	5.5	7.6	2.9	3.9	3.1	2.0	2.4	2.4	5.6
1909-10.....	12.9	7.1	8.5	10.5	7.0	8.7	8.4	5.4	6.6	5.5	3.4	4.1	2.1	2.5	2.0	1.9	1.9	1.9	5.0
1910-11.....	15.1	5.1	9.0	13.2	7.6	9.9	11.5	7.6	9.4	11.9	6.6	10.1	3.1	4.7	3.0	2.0	2.5	2.5	5.9
1911-12.....	6.3	2.8	4.0	7.7	4.1	4.7	9.3	5.9	7.4	9.6	3.9	6.0	2.3	2.9	2.3	1.4	1.8	1.8	3.3
1906-1912.....	26.8	2.8	7.4	13.2	4.1	8.7	12.1	5.1	8.0	11.9	3.4	7.0	2.1	3.9	4.5	1.4	2.4	2.4	4.8

Kennett is about 3 miles below the mouth of the Pit River and 323 miles above the mouth of the Sacramento. The drainage area above the station is 8,450 square miles. Besides the drainage of the elevated region of the Sacramento, this station also shows the output of the Pit. Kennett is really the starting point of all flood waves that affect the upper Sacramento River.

Red Bluff is 265 miles from the mouth of the River and 58 miles below Kennett. The drainage area above the station is 11,058 square miles. The average fall per mile between Kennett and Red Bluff is 6.6 feet. When the river at Red Bluff is at or near a 10-foot stage a 25-foot stage at Kennett will cause an additional rise at Red Bluff of 10 or 11 feet. It has been closely estimated that under these conditions the Kennett water will reach Red Bluff in between 13 and 14 hours.

Jacinto is 198 miles from the mouth of the river and 67 miles below Red Bluff. The drainage area above the station is about 14,000 square miles. The average fall per mile between Red Bluff and Jacinto is about 2.6 feet. The Red Bluff flood wave will usually reach Jacinto in about 20 hours, and a 10-foot stage at Jacinto will generally be augmented by about 6 feet from a 20-foot head at Red Bluff, eliminating, of course, the output of Stony Creek, which empties into the Sacramento 9 miles above Jacinto.

Colusa is 156 miles from the mouth of the river and 42 miles below Jacinto. The drainage area above the station is 15,943 square miles. The average fall per mile between Jacinto and Colusa is slightly over a foot. The Jacinto station has recently been established in the place of Monroeville, near the mouth of Stony Creek, which has been abandoned. The effect of Stony Creek flood discharge on the river at Jacinto and Colusa will be discussed in connection with the station at St. John on Stony Creek.

Knights Landing is 99 miles above the mouth of the river and 57 miles below Colusa. The drainage area above the station is 16,793 square miles. The average fall per mile between Colusa and Knights Landing is about 0.4 foot. The effect of high water at Colusa on points down the river depends altogether on the condition of the levees and on the amount of water in Colusa, Yolo, and Sutter Basins.

Sacramento City is at the junction of the Sacramento and American Rivers, and is 64 miles from the mouth of the river. It is 35 miles below Knights Landing and 20 miles below the mouth of the Feather River at Vernon. The drainage area above the station is 28,433 square miles. The average fall per mile between Knights Landing and Sacramento is about 0.5 of a foot.

Much of the flood waters of the Feather River escapes either into Sutter Basin or through breaks on the west side into Yolo Basin,



but a sufficient amount reaches Sacramento to cause a decided rise on the gage at that point.

Rio Vista is 26 miles from the mouth of the river and 38 miles below Sacramento City. The drainage area above the station is 30,047 square miles. The station is about 3 miles below the mouth of Steamboat Slough through which the drainage of the Coast Range and the accumulated waters of Yolo Basin are discharged into the Sacramento River.

#### TRIBUTARIES OF THE SACRAMENTO.

It would be practically impossible to enumerate all the small water-courses that feed the Sacramento River during periods of heavy rainfall, or even the streams that are kept alive during the rainy season, and no attempt will be made in this paper to name or describe any stream other than those that materially affect the water levels of the main river. The main and tributary streams of both valleys are shown in figure No. 1, frontispiece.

The most important tributaries of the Sacramento flow westward from the Sierra Nevada, the largest of which, named from north to south, are the Pit, Feather, and American Rivers. There are several creeks that run the greater part of the year, chief of which are Battle, Antelope, Mill, Deer, Chico, and Butte. While all of these creeks have heavy discharges in times of heavy rainfall it has not yet been practicable to establish permanent stations on any of them. They are, however, considered in times of floods.

The Pit River rises in the Warner Mountains at an elevation of some 10,000 feet and flows southwestward to its junction with the Sacramento about 3 miles north of Kennett. This river is really the northeastern extension of the Sacramento and some geographers consider the Pit and Sacramento as one stream. The total fall of the Pit is about 6,000 feet. From the mouth of Falls River, at Falls City, to where it joins the Sacramento, a distance of about 87 miles, the Pit is deeply intrenched in rocky canyons. The principal tributaries of the Pit are the McCloud and Falls Rivers, although Montgomery, Hatchet, Hat, Squaw, and Burney Creeks add greatly to its discharge during periods of heavy rainfall. In times of heavy flow the most of the creeks named practically leap into the Pit as roaring cataracts. There is no Weather Bureau gauging station on the Pit River, but, as has been stated, the combined output of the Pit and the upper Sacramento River is measured on the Kennett gauge where a rise of from 15 to 20 feet often occurs in 24 hours.

The precipitation of the Pit River drainage becomes somewhat less as the northeastern end of its watershed is approached, especially in the level portions of Modoc County. It increases in the higher levels

of the Warner Mountains, and varies from 20 to 30 inches annually. Some snow falls along the western slopes of the Warner Mountains and occasionally in the plains adjacent to Alturas. Within a radius of 20 to 40 miles adjacent to Kennett, in the lower Pit and upper Sacramento watersheds, the annual precipitation sometimes exceeds 100 inches. In 1909 the rainfall at Kennett for the three months ending with March was 86.42 inches, of which 54.08 inches fell in January and 24.30 in February. The annual precipitation at Kennett for 1909 was 115.92 inches.

The Feather River drains an extensive area south of the Honey Lake drainage basin and empties into the Sacramento at Vernon, 20 miles above Sacramento City. The drainage area above its mouth is something over 7,000 square miles. Its principal tributaries are the Yuba, which joins it near Marysville, and the Bear, which empties into it 17 miles below Marysville and 1 mile above Nicolaus. The output of the Feather River will probably exceed that of any of the tributaries of the Sacramento and is one of the principal streams to be reckoned with in times of flood. It rises on Mount Lassen at an elevation of nearly 10,000 feet and flows southward, being joined in the high Sierra by numerous forks, the chief of which are the North, Middle, and South Forks. The Feather-Yuba drainage includes the western slopes of the Sierra Nevada lying between the Pit and American Basins. The mean annual precipitation in the Feather-Yuba drainage area varies from 20 inches in the valley to 60 or 70 inches in the higher regions; occasionally as much as 100 inches falls. In the higher regions it is mostly in the form of snow, which often remains on the ground until June and sometimes July. On the summit of Mount Lassen the snow rarely ever disappears. From Oroville to its mouth the Feather flows practically parallel with the Sacramento, and during all floods of which there is a record it has overflowed its west bank at a point near Hamilton Bend and discharged its surplus water into a basin lying north of Marysville Buttes, thence into the Sacramento through Butte Slough. This water in 1909 was the deciding factor in the breaking of the levees at Moons Bend on the Sacramento River below Colusa and the flooding of Colusa Basin.

Upon the completion of an enormous dam by the Great Western Power Co. in the lower portion of Big Meadows Valley, that part of the North Fork of the Feather which drains this valley will be changed into a large reservoir that will occupy an area of about 40 square miles. The dam, which will impound about 1,250,000 acre-feet of water, will be 110 feet above the ordinary water level of the valley. As the North Fork of the Feather, besides bearing the drainage of Mount Lassen, is the most extensive watershed of any of the branches of this river, it will be seen that this huge reservoir will exercise a modifying effect on future flood conditions in the main stream. A

regular river and rainfall station is maintained at Oroville on the Feather, 32 miles above its confluence with the Yuba and 50 miles from the mouth of the river. The drainage area above the station is 3,100 square miles. The fall between Oroville and the mouth of the Feather is about 2.6 feet per mile. Another regular river and rainfall station has recently been established on the Feather at Nicolaus, 16 miles below the mouth of the Yuba, 1 mile below the mouth of the Bear, and 10 miles above the mouth of the Feather.

The Yuba River rises at an elevation of about 8,000 feet and flows southwestward to its junction with the Feather near Marysville. It is fed by three forks, the North, Middle, and South, which drain the snow fields of the high mountains. A regular river and rainfall station has been maintained for many years at Marysville, which is 26 miles above the mouth of the river. The drainage area above Marysville is 3,540 square miles. In times of flood or heavy rainfall special telegraphic reports are received from Downieville, on the North Fork of the Yuba, about 95 miles above Marysville.

The Bear River drains a small area, not over 300 square miles, between the Yuba and American watersheds. It rises at an elevation of about 5,500 feet and flows southwestward to its junction with the Feather. This stream rises rapidly under the influence of heavy rains or melting snows in the higher regions of its watershed. With the cessation of rain the river quickly subsides and reaches its normal stage in a few hours' time. A special river station has been established on the Bear near Colfax, from which telegraphic reports are received in times of heavy rainfall.

The American River drains that part of the western slopes of the Sierra Nevada lying between the Bear and Yuba on the north and the Cosumnes and Mokelumne on the south. It flows southwestward and joins the Sacramento at the city of Sacramento. The drainage area above its mouth is about 2,000 square miles and its total fall is about 9,000 feet. Like the Feather and Yuba Rivers, the American branches out into numerous forks, all of which tap the snow fields of the high mountain ranges. In the higher part of its basin are numerous small lakes. There are two stations on this stream: One at Folsom, 25 miles above Sacramento, from which reports of river and rainfall are received the year round, and another on the Middle Fork, near East Auburn, from which reports are telegraphed in times of high water or heavy rainfall. It has been estimated that when a stage of 10 feet is reached on the Middle Fork gauge, assuming that all other forks are proportionally high, the main river at Folsom will be augmented by 10 or 11 feet when the gauge at the last-named point is at or near a 10-foot stage. The advance flood wave, starting at Folsom with a 20-foot head, will reach Sacramento city in about six hours. With a 25-foot head at Folsom the swell will be felt at

Sacramento in about five hours. The rate of progress of this stream becomes rapidly less as the water subsides, and at extreme low water the river becomes very sluggish, especially in the vicinity of Sacramento. Between Fair Oaks and Folsom the river is mostly confined within high banks. The American rarely retains a full head of water longer than a few hours after the cessation of rain, and for this reason its flood waves usually pass into the Sacramento before the output of the Feather-Yuba reaches its mouth. However, with a protracted spell of heavy rainfall that is coextensive with the watersheds of the American, Feather, and Yuba Rivers, the American remains at flood stage until the approach of the Feather River output, or such a part thereof as does not escape into the basins on each side of the Sacramento above the mouth of the American. The mean annual precipitation of the American watershed varies from 20 inches in the vicinity of Sacramento to 25 or 30 inches in the foothills. In the higher regions it amounts to 60 or 70 inches, and much of it is in the form of snow. Melting snows in the higher regions affect the American during the first warm days of spring, but this of itself rarely raises the river more than a few feet, and this usually flattens out before reaching Sacramento. The most potent factor in producing floods in the American is the combined influence of heavy rainfall and melting snows in its upper watershed.

Of the western tributaries of the Sacramento or those that flow from the Coast Range, the most important are Stony, Cache, Putah, and Cottonwood Creeks. In addition to these are Clear and Thomas Creeks, streams of small discharges and restricted watersheds.

Cottonwood Creek empties into the Sacramento near the town of Cottonwood. Its numerous small forks rise in the Coast Range at elevations ranging from 4,000 to over 6,000 feet. Although the main stream is east of the Coast Range proper, the total area drained by this creek is something over 900 square miles. The mean annual precipitation ranges from 20 to 25 inches in that part contiguous to the Sacramento River to 50 inches or more in the higher regions, where much of it is in the form of snow. This stream has a heavy discharge during periods of excessive rainfall, but it has not yet been practicable to establish a Weather Bureau river gauge in its watershed.

Stony Creek rises west of the Sacramento River at an elevation of about 5,000 feet and flows northward between the Coast Range proper and the foothills until it breaks through the hills and turns eastward through the plains toward the Sacramento, into which it discharges at a point near Monroeville. Stony Creek is the last southerly watercourse that discharges directly into the Sacramento River. The mean annual precipitation in the watershed of Stony Creek varies from 25 inches in the valley to about 40 inches in its

most elevated feeders. Some snow falls in the higher regions, but this form of precipitation is rarely a factor in the flood situation.

The Weather Bureau maintains a regular river and rainfall station at St. John, about 3 miles above the point where the creek joins the Sacramento River, and a special rainfall station is in operation at Stonyford, about 45 miles above St. John, from which heavy rainfall is reported by telegraph. During the summer months the creek in the vicinity of St. John is practically dry, but during the winter months, especially during periods of heavy rainfall it rises rapidly, sometimes carrying away bridges, as was the case during the floods of 1907 and 1909. Stages over 6 feet in the lower reaches of the creek exercise a marked influence on the run-off of the Sacramento between its junction with the Sacramento and Colusa. Records show that stages between 9 and 12 feet on the St. John gauge will raise the river in the vicinity of Colusa from 5 to 7 feet when the Colusa gauge is at or near a 15-foot stage. The distance from the mouth of Stony to Colusa is about 50 miles and the first effect of the Stony flood wave is felt in between 14 and 16 hours, according to the intensity of the wave. The average fall per mile between the mouth of the creek and Colusa is about 2.3 feet. The creek falls rapidly after the cessation of rain and rarely maintains a stage as high as 8 feet for more than a few hours. At 12 feet the creek overflows its banks in the vicinity of St. John.

The United States Reclamation Service has recently completed a large reservoir in the vicinity of Orland, where a sufficient amount of water has been impounded from Stony Creek to irrigate some 14,000 acres.

Cache Creek drains that part of the eastern slope of the Coast Range lying between Stony and Putah Creeks. It rises in Clear Lake and flows southward through Yolo Basin and reaches the Sacramento River through Cache and Steamboat Sloughs a short distance above Rio Vista. Clear Lake has a drainage basin of about 450 square miles.

Putah Creek drainage basin lies between Cache Creek and Napa Valley. It rises in the St. Helena Range and flows southward through Yolo Basin, thence through Cache and Steamboat Sloughs into the Sacramento River.

The mean annual precipitation in the Cache and Putah Creek Basins varies from about 20 inches in Yolo Basin to 50 or 60 inches in the higher regions. Some snow falls in the upper forks of Putah and in the feeders of Clear Lake, although there is no appreciable increase in the run-off of either stream from this form of precipitation.

Both Cache and Putah Creeks have a heavy discharge during periods of heavy rainfall, and their flood waters intensify conditions from Rio Vista to Collinsville and throughout the island districts in



the lower Sacramento and San Joaquin Rivers. All water that reaches Yolo Basin, whether from the hills or from the overflow of Colusa Basin, or through weirs and other openings along the west side of the Sacramento River, is borne back into the Sacramento River through the outlets that carry the combined discharge of Cache and Putah Creeks. During the floods of 1907 and 1909 the discharge of the accumulated water of Yolo Basin into the Sacramento River was sufficient to reverse the current of this stream for several miles above the mouth of Steamboat Slough, especially during flood tide.

No Weather Bureau gauges have been established on Cache or Putah Creeks, but arrangements are being made whereby gauge readings may be secured from several points in Yolo Basin during flood periods.

#### THE SAN JOAQUIN DRAINAGE BASIN.

The San Joaquin Valley is bounded on the east by the Sierra Nevada, on the south by the Tehachapi Cross Range, on the west by the Coast Range; on the south it merges into the Sacramento Valley in the region of the Mokelumne and Cosumnes Rivers.

The San Joaquin River, the trunk stream of the southern end of the Great Valley, and of the San Joaquin Valley, rises in the elevated regions of the Southern Sierras at a point south of the Yosemite National Park and flows southward to the floor of the valley, thence northwestward to Suisun Bay. Its total length is quoted as 350 miles. The river has been popularly divided into two sections, the upper and lower. The logical point between the divisions is a few miles above Mendota, where the river bends abruptly from a southwesterly to a northwesterly course.

Precipitation in the valley itself, or along the course of the river, ranges from something over 16 inches annually in the vicinity of Stockton to less than 5 inches in the region of Bakersfield. It increases rapidly as the Sierra Nevada are approached. The main water supply, however, of this stream is drawn from melting snows from the high mountain peaks of the Southern Sierra, many of which are almost always covered with snow. For this reason the mean maximum flow generally occurs in May and June, sometimes in July.

Three river and rainfall stations, having uninterrupted records of six years, are maintained on the San Joaquin River proper. Named from south to north they are Friant, Firebaugh, and San Joaquin Bridge.

Tables of highest, lowest, and mean stages for each month and the mean for each year follow.

The tabular values are also presented graphically in figures 16 to 22b, inclusive.

Mean monthly river stages, San Joaquin system.

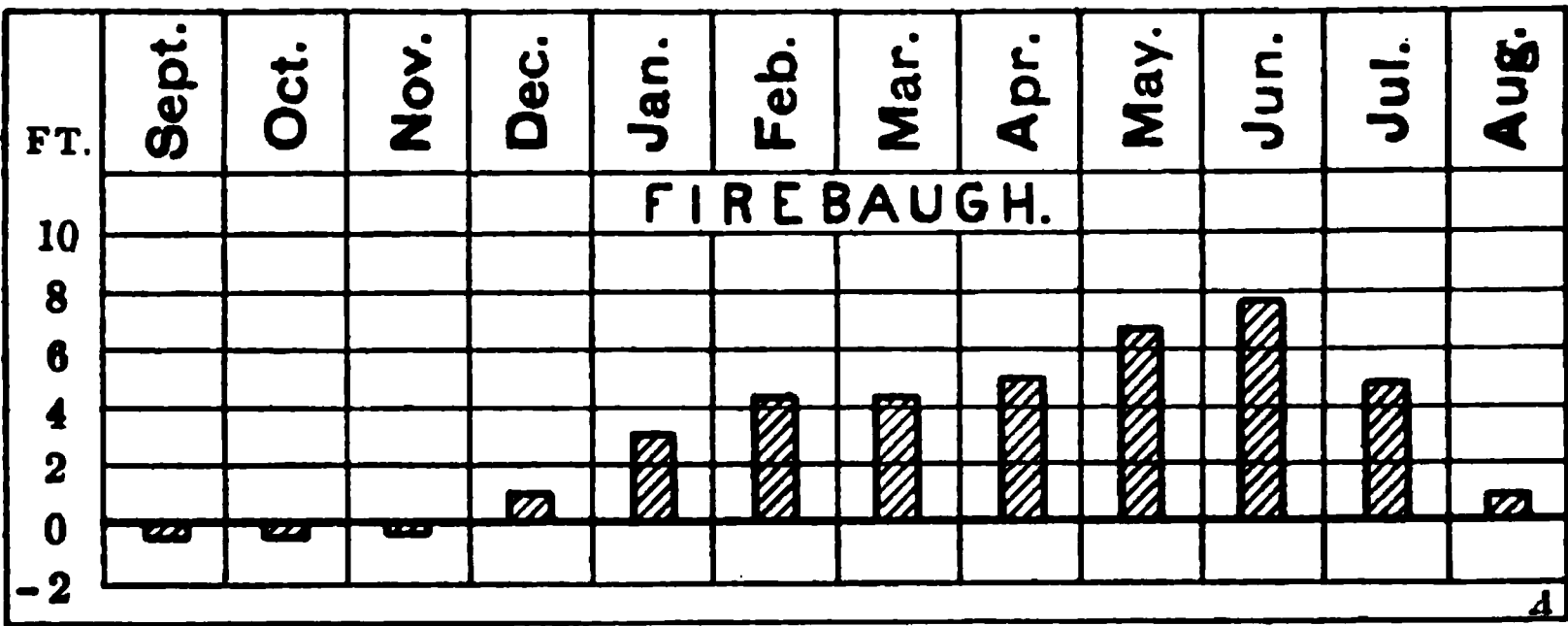


FIG. 16.—Mean monthly river stages.

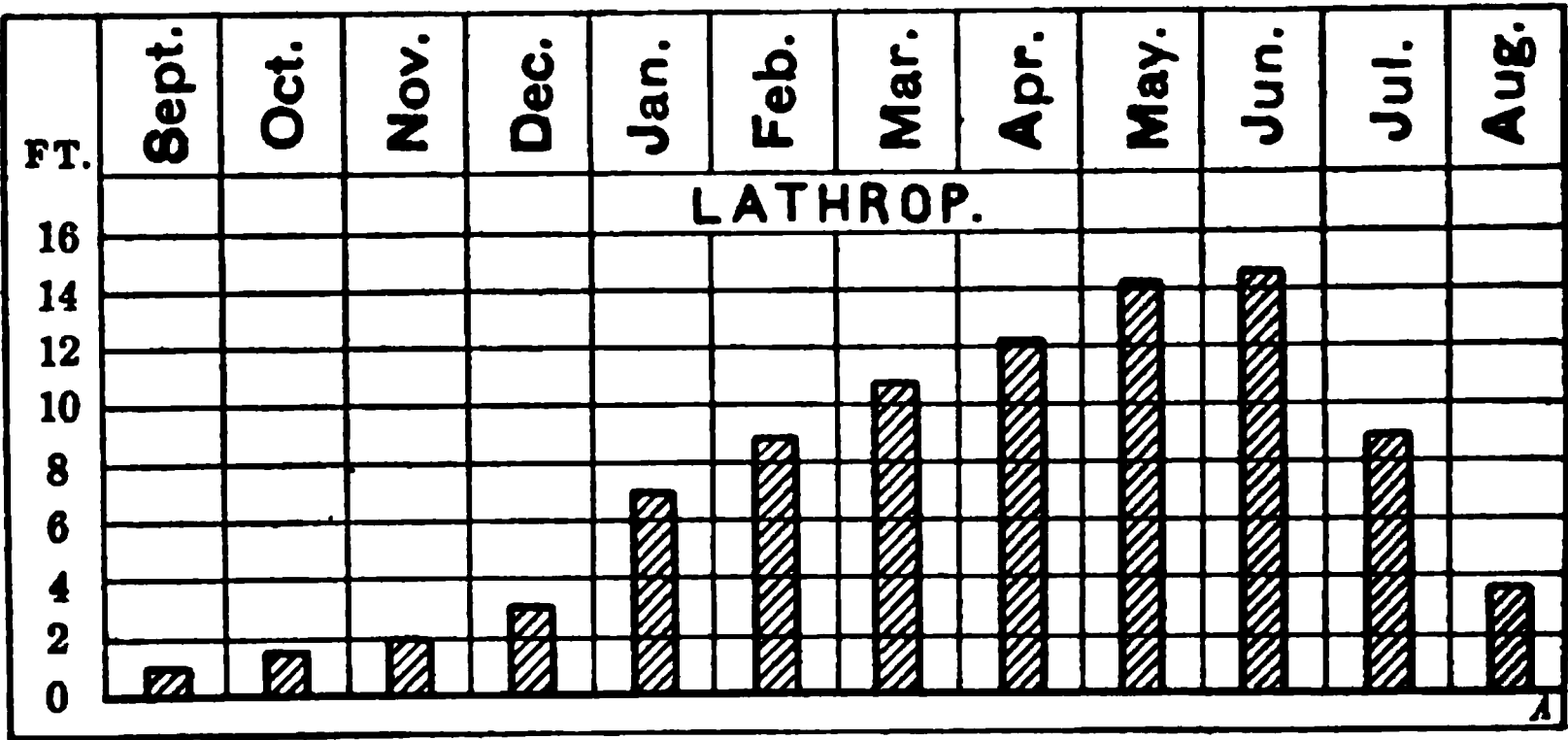


FIG. 16a.—Mean monthly river stages.

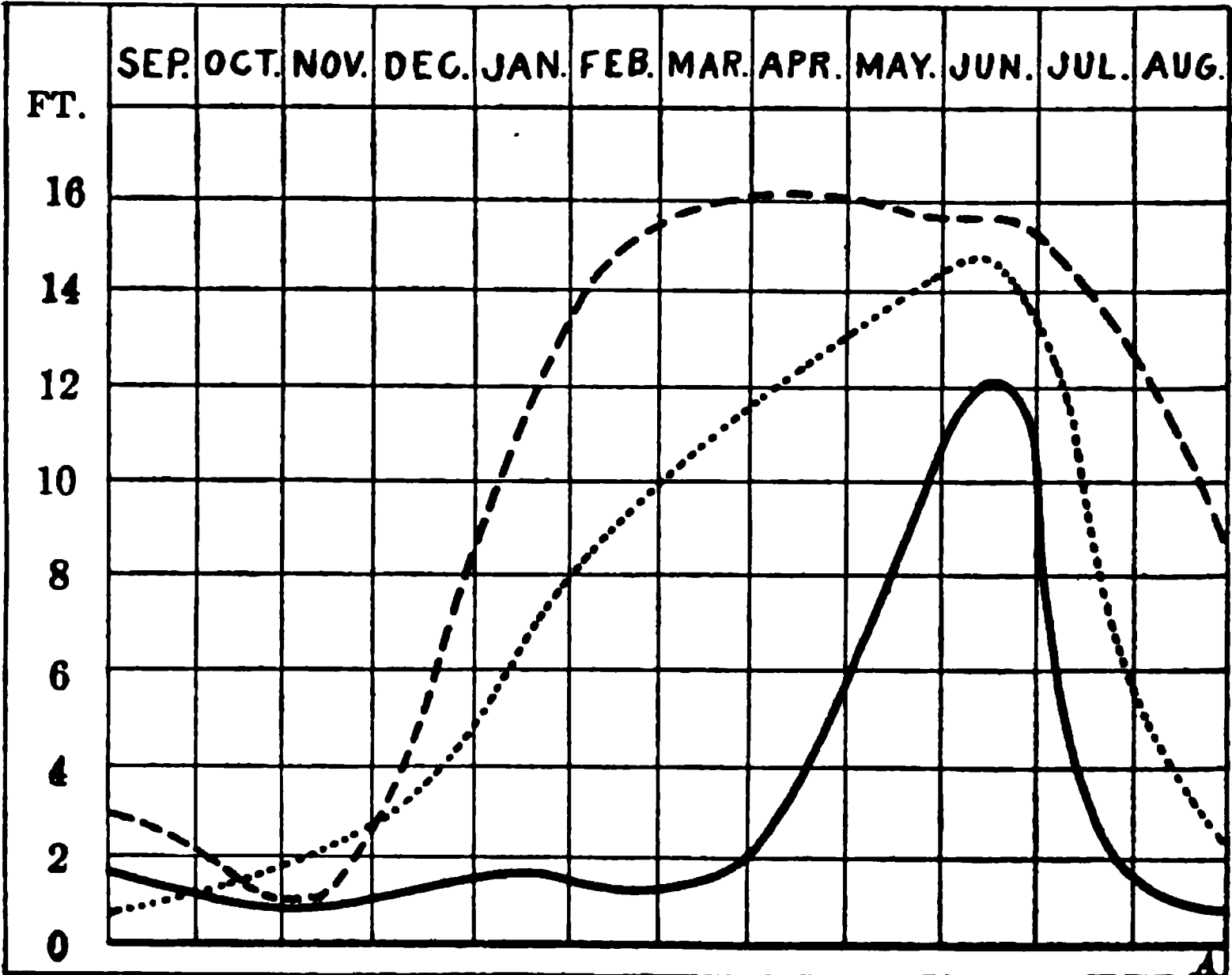


FIG. 17.—Mean monthly river stages, Lathrop, Cal. Broken line, season 1906-7, unusually high; solid line, 1911-12, unusually low; dotted line, mean stages for a 12-year period.



*Highest, lowest, and mean seasonal stages, San Joaquin system.  
(In feet.)*

FIG. 18.—Highest, lowest, and mean stages.

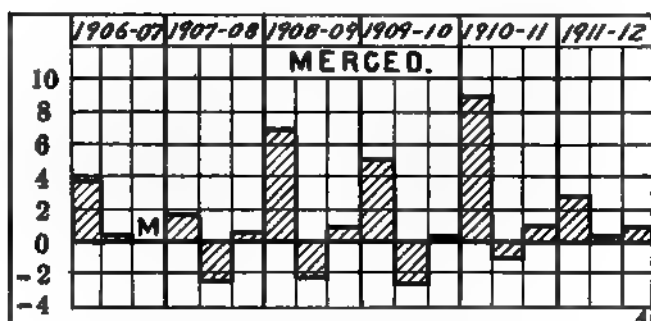


FIG. 19.—Highest, lowest, and mean stages.

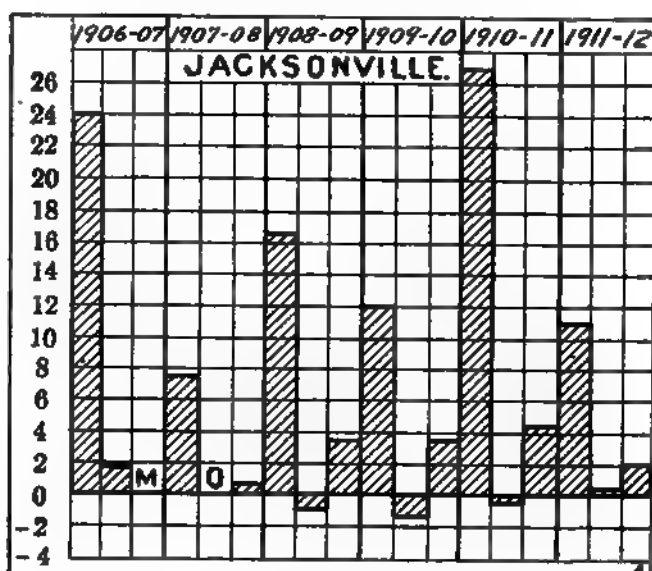


FIG. 20.—Highest, lowest, and mean stages.

*Highest, lowest, and mean seasonal stages, San Joaquin system—Continued.*  
(In feet.)

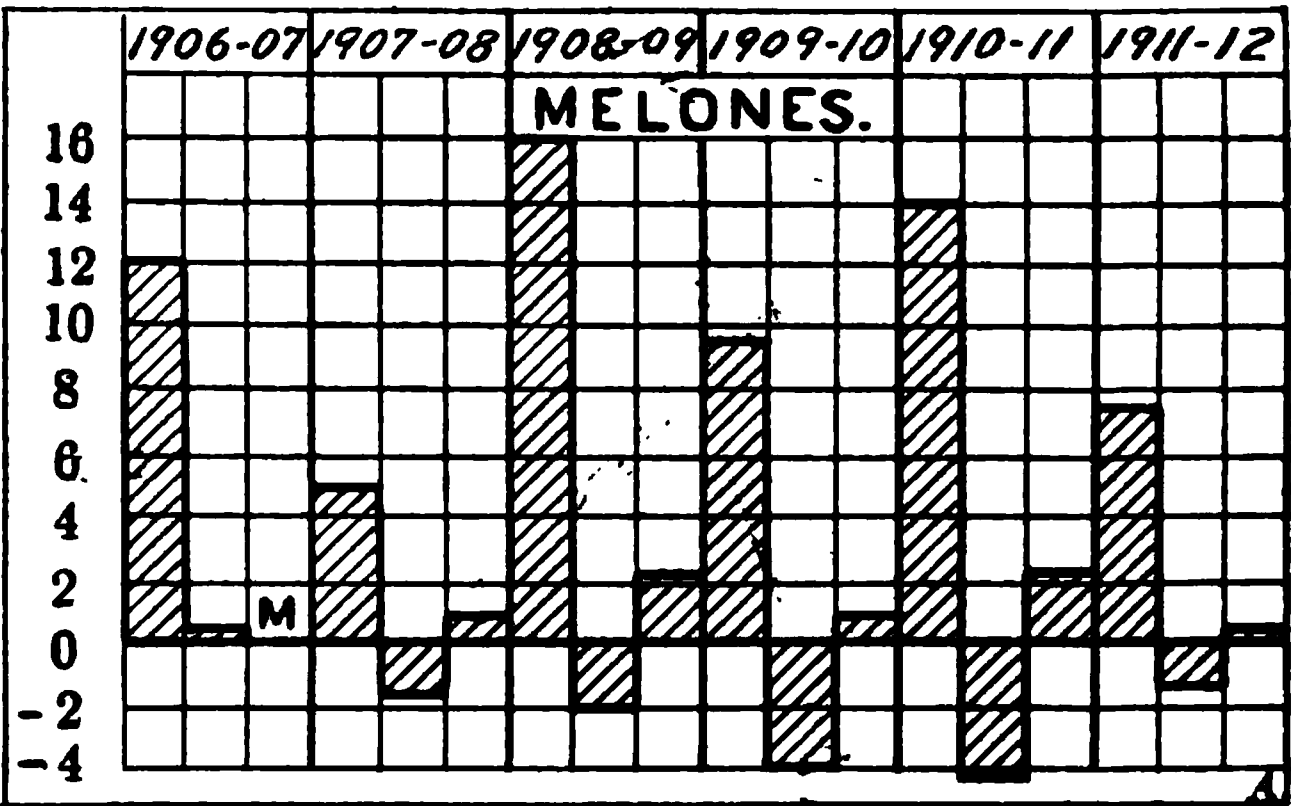


FIG. 20a.—Highest, lowest, and mean stages.

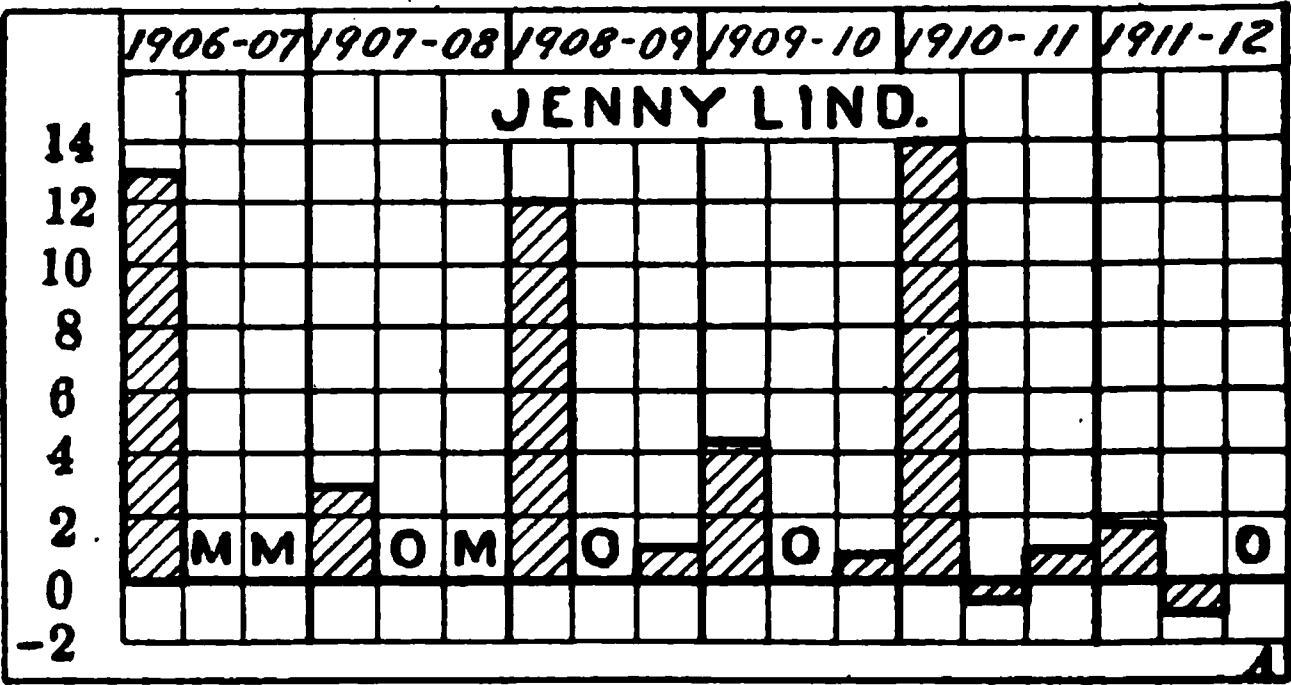


FIG. 20b.—Highest, lowest, and mean stages.

*Highest, lowest, and mean seasonal stages, San Joaquin system Continued.*

(In feet.)

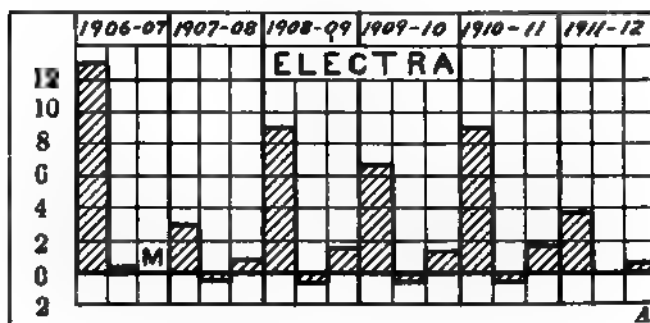


FIG. 21.—Highest, lowest, and mean stages.

FIG. 22.—Highest, lowest, and mean stages.

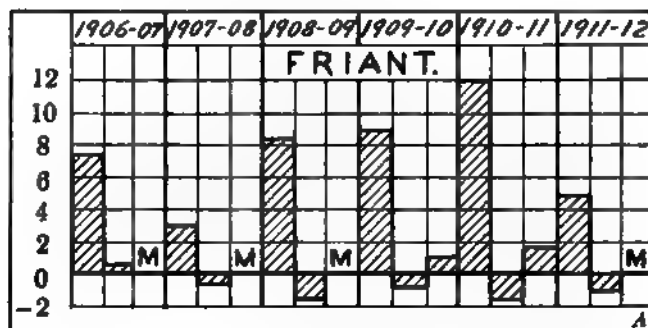


FIG. 22b.—Highest, lowest, and mean stages.

SAN JOAQUIN RIVER SYSTEM.

TABLE No. 1.—Highest, lowest, and mean stages for each month and the mean for each year at Friant.

Stages in bold-face type indicate the extremes for each year.  
Friant is on the San Joaquin River, 203 miles from its mouth, and 43 miles above Firebaugh. Elevation, 355 feet; flood stage, 10 feet.

Year.	September.			October.			November.			December.			January.			February.					
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.			
1906-7.....	2.0	1.2	1.7													4.0	0.6	1.3	2.5	1.4	1.9
1907-8.....		.2	.0													.9	.0	.1	.9	.0	.1
1908-9.....		.0	.0													<b>8.5</b>	.0	1.9	5.3	.9	1.7
1909-10.....		.0	.0													<b>9.0</b>	.8	1.8	1.0	.5	.7
1910-11.....		2.3	-1.0													<b>12.0</b>	-1.3	1.0	6.0	1.0	2.1
1911-12.....		.5	-.2													-.6	-.6	-.6	-.6	-.6	-.6
1906-12.....		2.3	-1.0													12.0	-1.3	.9	6.0	-.6	1.0

Year.	March.			April.			May.			June.			July.			August.			Annual.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1906-7.....	7.5	1.3	3.3	5.9	2.8	7.4	4.1	5.4	8.0	3.8	5.8	6.4	3.0	4.6	3.0	2.1	2.6		
1907-8.....	1.5	.3	.9	3.0	.3	<b>3.2</b>	.7	1.7	1.9	1.0	1.4	1.1	.3	.6	1.3	.0	.2		
1908-9.....	1.7	.9	1.2	4.0	1.0	5.7	3.5	4.5	7.6	4.0	5.7								
1909-10.....	2.0	.5	1.3	4.3	.7	4.0	2.4	3.4	4.1	1.3	2.0	1.3	-.1	.3	-.1	-0.6	-.4	1.0	
1910-11.....	6.8	1.0	2.8	4.8	2.1	6.2	3.0	4.2	7.8	3.8	6.3	6.0	2.3	4.5	2.2	.5	1.3	1.8	
1911-12.....	.9	-.6	-.1	.8	-.2	4.6	.5	1.8	<b>4.9</b>	.7	2.6								
1906-12.....	7.5	-.6	1.6	5.9	-.2	7.4	.5	3.5	8.0	.7	4.3	6.4	-.1	2.5	3.0	-.6	.9		





TABLE NO. 4.—Highest, lowest, and mean stages for each month and the mean for each year at Merced Falls.

Stages in bold-face type indicate the extremes for each year.  
Merced Falls is on the Merced River, 35 miles from its mouth. Elevation about 321.1 feet. There is no danger from floods.

Year.	September.			October.			November.			December.			January.			February.		
	High.		Low.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1906-7.....	0.4	0.0	0.2	0.8	0.0	0.1	0.2	0.0	0.0	0.7	0.0	0.3	4.0	0.5	1.0	2.1	0.8	1.2
1907-8.....													1.1	.4	.5	.8	.3	.4
1908-9.....	.0	-2.0	-.8	.3	-2.0	-1.0	.0	-2.0	-1.0	.0	-2.0	-.9	7.1	-.9	1.5	4.9	1.0	1.7
1909-10.....	.2	-2.6	-1.0	.0	-2.0	-.7	1.3	-1.0	.2	4.8	.4	.8	5.3	.7	1.3	1.0	.7	.8
1910-11.....	.7	-1.0	-.8	.0	-1.0	-.4	.2	-1.0	-.5	.8	-1.0	-.3	9.0	-1.0	1.1	4.1	1.0	1.6
1911-12.....	.5	.4	.3	.3	.3	.3	.4	.3	.3	.3	.2	.2	.5	.2	.4	.4	.3	.4
1906-12.....	.7	-2.6	-.4	.8	-2.0	-.3	1.3	-2.0	-.2	4.8	-2.0	.0	9.0	-1.0	1.0	4.9	.3	1.0

Year.	March.			April.			May.			June.			July.			August.			An- nual.
	High.		Low.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1906-7.....	6.0	0.9	2.5	2.9	1.7	2.4	3.5	2.1	2.7	1.6	1.7	2.7	1.0	1.7	1.2	0.4	0.7	.....	0.5
1907-8.....	1.1	.6	.8	2.0	.6	1.2	1.9	1.0	1.3	.7	1.0	1.0	.3	.5	.5	-2.4	-.4	.....	0.5
1908-9.....	1.4	.9	1.0	2.4	1.0	1.6	3.1	2.0	2.5	1.8	1.8	2.7	.5	1.0	.5	-.7	-.3	.....	.7
1909-10.....	2.1	.8	1.3	2.8	1.3	2.0	2.4	1.5	2.0	.5	1.5	1.0	.0	.4	.0	-1.0	-.8	.....	.3
1910-11.....	5.2	1.4	2.5	2.8	1.7	2.1	3.5	2.0	2.5	2.4	3.3	3.0	1.0	1.9	1.0	.5	.7	.....	1.1
1911-12.....	1.5	.3	.8	1.5	.6	.9	2.8	.9	1.6	.8	1.7	1.7	.3	.5	.3	.2	.3	.....	.6
1906-12.....	6.0	.3	1.5	2.9	.6	1.7	3.5	.9	2.1	.5	2.1	2.1	.0	1.0	1.2	-2.4	.1	.....	.6





TABLE NO. 6.--Highest, lowest, and mean stages for each month and the mean for each year at Melones.

Stages in bold-face type indicate the extremes for each year.  
Melones is on the Stanislaus River, 64 miles from its mouth. No danger from floods.

Year.	September.			October.			November.			December.			January.			February.		
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1906-7.....	0.2	-0.2	0.0	-0.2	-0.3	-0.3	-0.1	-0.6	-0.3	1.1	-0.6	0.4	5.2	1.0	1.7	6.0	3.4	4.1
1907-8.....	-1.2	-1.8	-1.7	-1.4	-1.9	-1.6	-1.0	-1.9	-1.6	.2	-1.4	-.2	0.7	-.9	.1	.0	-.9	-.3
1908-9.....	-1.9	-3.6	-3.2	-.5	-2.7	-1.3	9.5	.5	1.9	9.4	.5	2.8	16.0	-.5	3.8	7.0	2.5	3.7
1909-10.....	-3.4	-4.1	-4.0	-3.9	-4.0	-4.0	-1.5	-3.9	-3.2	.5	-.7	.2	6.0	.3	2.4	3.0	1.8	2.4
1910-11.....	1.0	.9	.9	.9	.7	.8	.5	-.1	-.0	.0	-.3	-.1	14.0	-1.0	2.4	8.0	1.8	3.1
1911-12.....	1.0	-4.1	-1.6	.9	-4.0	-1.3	9.5	-3.9	-.6	9.4	-1.4	.6	1.2	-.2	.0	.7	-.5	.4
1906-1912.....	1.0	-4.1	-1.6	.9	-4.0	-1.3	9.5	-3.9	-.6	9.4	-1.4	.6	16.0	-1.0	1.7	8.0	-.9	2.2

Year.	March.			April.			May.			June.			July.			August.			An- nual.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1906-7.....	12.2	3.2	6.0	5.6	3.2	4.5	6.2	4.5	5.1	7.0	5.2	6.2	6.8	2.0	4.0	0.1	1.2	1.2	.....
1907-8.....	2.3	-.7	1.2	4.9	1.0	2.9	4.0	2.3	2.9	2.8	2.0	2.4	2.2	-.4	.0	-1.2	-.8	-.8	0.7
1908-9.....	4.0	2.3	3.0	9.0	3.0	5.6	9.1	4.5	6.8	9.5	4.2	6.4	4.5	1.0	2.7	-1.6	-.8	-.8	2.2
1909-10.....	8.0	3.5	5.1	7.8	4.0	6.1	6.5	4.2	5.1	5.2	.2	2.3	.3	-2.0	-2.0	-4.0	-3.8	-3.8	.7
1910-11.....	8.0	1.8	5.0	9.0	4.5	6.4	10.0	5.0	7.0	10.9	5.5	8.7	6.0	1.8	3.2	1.0	1.2	1.2	2.2
1911-12.....	1.3	.0	.7	2.5	.8	1.3	6.5	1.5	4.2	7.3	1.0	3.7	1.0	-.1	.4	-.9	-.6	-.6	.1
1906-1912.....	12.2	-.7	3.5	9.0	.8	4.5	10.0	1.5	5.2	10.9	.2	5.0	6.8	-2.0	1.4	-4.0	-.6	-.6	1.2



TABLE NO. 6.—Highest, lowest, and mean stages for each month and the mean for each year at Melones.  
Stages in bold-face type indicate the extremes for each year.  
Melones is on the Stanislaus River, 64 miles from its mouth. No danger from floods.

Year.	September.			October.			November.			December.			January.			February.		
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1906-7.....	0.2	-0.2	0.0	-0.2	-0.3	-0.3	-0.1	-0.6	-0.3	1.1	-0.6	.....	5.2	1.0	1.7	6.0	3.4	4.1
1907-8.....	-1.2	-1.8	-1.7	-1.4	-1.9	-1.6	-1.0	-1.9	-1.6	.....	.....	.....	0.7	.....	.....	.....	.....	.....
1908-9.....	-1.9	-3.6	-3.2	.....	-2.7	-1.3	.....	.....	.....	.....	.....	.....	16.0	.....	.....	.....	.....	.....
1909-10.....	-3.4	-4.1	-4.0	-3.9	-4.0	-4.0	-1.5	-3.9	1.9	9.4	.....	.....	6.0	.....	.....	.....	.....	.....
1910-11.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	14.0	.....	.....	.....	.....	.....
1911-12.....	1.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1906-1912.....	1.0	-4.1	-1.6	.....	-4.0	-1.3	9.5	-3.9	.....	9.4	-1.4	.....	16.0	-1.0	1.7	8.0	.....	2.2

Year.	March.			April.			May.			June.			July.			August.			Annual.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1906-7.....	12.2	3.2	6.0	5.6	3.2	4.5	6.2	4.5	5.1	7.0	5.2	6.2	6.8	2.0	4.0	0.1	1.2	.....	.....
1907-8.....	2.3	.....	1.2	4.9	1.0	2.9	4.0	2.3	2.9	2.8	2.0	2.4	2.2	.....	.....	.....	.....	.....	.....
1908-9.....	4.0	2.3	3.0	9.0	3.0	5.6	9.1	4.5	6.8	9.5	4.2	6.4	4.5	.....	.....	.....	.....	.....	.....
1909-10.....	8.0	3.5	5.1	7.8	4.0	6.1	6.5	4.2	5.1	5.2	.....	2.3	.....	.....	.....	.....	.....	.....	.....
1910-11.....	8.0	1.8	5.0	9.0	4.5	6.4	10.0	5.0	7.0	10.9	5.5	8.7	6.0	.....	.....	.....	.....	.....	.....
1911-12.....	1.3	.....	.....	2.5	.....	1.3	6.5	1.5	4.2	7.3	1.0	3.7	1.0	.....	.....	.....	.....	.....	.....
1906-1912.....	12.2	.....	3.5	9.0	.....	4.5	10.0	1.5	5.2	10.9	.....	5.0	6.8	.....	1.4	.....	.....	.....	1.2



TABLE NO. 8.—Highest, lowest, and mean stages for each month and the mean for each year at Electra.

Stages in bold-face type indicate the extremes for each year.  
Electra is on the Mokelumne River 70 miles from its mouth and 55 miles above its junction with the Cosumnes River. Elevation, 669.8 feet; flood stage, 12 feet.

Year.	September.			October.			November.			December.			January.			February.		
	March.			April.			May.			June.			July.			August.		
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1906-7.....	13.0	2.2	4.0	3.6	2.6	3.1	3.8	2.4	3.1	4.6	2.4	3.4	3.8	1.6	2.6	0.1	0.7	.....
1907-8.....	1.2	.7	1.0	2.8	.9	1.9	2.4	1.2	1.8	2.4	.7	1.6	3.7	.5	.5	.2	—	0.7
1908-9.....	2.6	1.8	2.4	3.5	2.2	2.5	4.0	3.2	3.6	4.6	3.0	3.9	3.0	.1	.9	—	—	1.5
1909-10.....	4.0	1.4	2.6	3.8	2.2	3.0	3.6	2.8	3.2	3.1	.9	1.7	.9	.0	.3	—	—	1.4
1910-11.....	4.5	1.4	2.7	4.6	2.4	3.2	4.5	2.5	3.3	5.1	3.0	4.3	3.2	.7	2.1	.1	.2	1.7
1911-12.....	1.3	.2	.6	1.6	.6	.9	3.7	1.5	2.5	3.8	.8	2.1	.7	.0	.2	.0	.0	.6
1906-1912.....	13.0	.2	2.2	4.6	.6	2.4	4.5	1.2	2.9	5.1	.7	2.8	3.8	.0	1.1	—	.2	1.2

Friant is about 203 miles above the mouth of the river with a drainage area above the station of 1,730 square miles.

Firebaugh is 43 miles below Friant with a drainage area above the station of 11,382 square miles. San Joaquin is 111 miles below Firebaugh and 49 miles above the mouth of the river. The drainage area above the station is 20,887 square miles.

The average fall per mile between Friant and San Joaquin Bridge is about 2 feet; from San Joaquin Bridge to the mouth of the river the fall is only a fraction of a foot per mile.

#### TRIBUTARIES OF TULARE AND BUENA VISTA LAKES.

There are several streams that enter the San Joaquin Valley from the Sierras south of the upper end of the San Joaquin River that are lost in Tulare and Buena Vista Lakes and the adjacent "Tules." They are the Kern, Kaweah, Tule, and Kings Rivers.

The Kern has its source at elevations ranging between 11,000 and 13,000 feet, with a drainage basin quoted as 2,500 square miles. It flows southwestward from the mountains and empties into Buena Vista Lake. During exceptionally high stages in this lake it has been known to escape thence through various sloughs northward into Tulare Lake. While the Kern has a heavy discharge when in flood, and has been known to cause disastrous inundations, much of its normal flow is now diverted in the vicinity of Bakersfield for irrigation purposes.

The mean annual precipitation in the Kern River Basin varies from less than 5 inches in the valley to as much as 50 or 60 inches in the higher regions. Above the 5,000-foot level it is mostly all in the form of snow.

Tule River Basin, north of that of the Kern, starts in the high mountain ranges of the Sierra Nevada at an elevation quoted as 9,000 feet and flows westward toward Tulare Lake, which it sometimes reaches, but the most of its normal flow is now diverted for irrigation purposes in the vicinity of Porterville. Its watershed is small, the total drainage being quoted as 350 square miles.

The Kaweah River flows southwestward from the Great Western Divide and at high stages reaches Tulare Lake. Its greatest elevation is about 12,000 feet, and its drainage basin is about twice that of the Tule. Below the foothills the most of its flow is used for irrigation. Both the Tule and Kaweah are subject to overflow and occasionally some damage is caused from floods in the vicinity of Porterville on the Tule and Visalia on the Kaweah. The mean annual precipitation in the Kaweah and Tule Basins varies from 8 or 10 inches in the valley to 30 or 40 inches in the higher regions. Heavy snow falls in the most elevated regions of both watersheds.

The Weather Bureau has recently established several stations on the Kaweah River, the most important being at Carter's ranch, near Three Rivers.

Kings River drains the western slopes of the Sierras between the Kaweah drainage and that of the upper end of the San Joaquin. It rises at an elevation of nearly 14,000 feet and flows southwestward to a point just north of Tulare Lake, where it separates, one part flowing southward into the lake and the other northward through Kings River Slough into the San Joaquin. This stream, however, has rarely augmented, to any great extent, floods in the upper San Joaquin for the reason that at high stages its greatest discharge follows its southern course to the lake. Its main stream is tapped just below the foothills and a large part of its normal flow is diverted for irrigation purposes. The mean annual precipitation in the Kings River Basin ranges from as much as 60 inches or more in the higher regions to as little as 8 inches in its lower reaches.

All streams lying south of the upper end of the San Joaquin River which have been ponded back by Tulare and Buena Vista Lakes will, no doubt, be used more and more for irrigation purposes as the cultivated area increases, which will ultimately result in the reclaiming of the entire Tulare Lake Basin.

Owing to the fluctuations of the water level of the Tulare Lake considerable interest has, during the past few years, been centered around this section. Although millions of dollars have been lost in farming ventures by the inundation of lands in the vicinity of the lake thought to have become permanently arable, farmers still look forward to the time when the entire basin, or the "Valley of the Tules," as it is sometimes called, will be added to the agricultural assets of the State.

No better description of Tulare Lake itself, and the conditions that have prevailed in that section during the past 10 or 15 years, can be found than that published by the United States Geological Survey in Water-Supply Paper No. 251, which is as follows:

Tulare Lake is a shallow body of water occupying the lowest depression in the Tulare Basin. The lake is rectangular in shape and its greatest length is from northwest to southeast. In November, 1907, when the margin was carefully determined, the lake had an area of 274 square miles, a maximum depth of 12.4 feet, and average length of 20 miles, and a width of 13.5 miles; the water's edge was 3 miles from the town of Corcoran, and the water surface about 12 feet below. The lake reached its greatest height in the summer of 1907, when it had a maximum depth of nearly 14 feet.

For the 25 years preceeding 1898 the lake level was steadily lowered, with only seasonal fluctuations. This lowering was brought about by the development of irrigation in the Tulare Basin, the water used for this purpose being diverted from the streams supplying the lake; but undoubtedly the chief factor in producing the subsidence was light precipitation. During this entire period the precipitation was generally below the normal, particularly during the several years immediately preceding 1898, and in that year the lake became practically dry, and after having partially refilled in 1901, it became completely dry in 1905. As the water receded



a constantly increasing area of exceedingly fertile land was uncovered. From time to time this land was leveed on the lake side and cultivated, until, in the early spring of 1906, the entire bed was under cultivation.

On March 15, 1906, the first water reached the lake bed at the mouth of Kings River and began spreading over a large area of bottom land, upon which stood a crop of wheat almost matured. A few days later water from the Kaweah and Tule Rivers reached the lake. Then began a steady rise which rapidly submerged an increasingly large area of wheat fields. On June 1, the water was 7 feet deep, and covered 200 square miles. On June 23, overflow from the Kern Basin cut through the sand ridge from the south and flowed into the lake, which, for a few days afterwards rose at the rate of 0.2 foot per day. On August 4 the water reached its greatest height for the year 1906, and the lake had an area of about 300 square miles and a maximum depth of 12.7 feet. The total rise of the lake in 1906 was 10.8 feet. From this date the lake slowly subsided until December, after which a rise began which continued until July, 1907, when the lake attained a maximum depth of 14 feet. Since that date it has been gradually subsiding.

The lake bed resembles a large flat saucer, the flat, level area in the bottom has an elevation approximately 180 feet above mean sea level and covers about 55 square miles. The lowest point on the crest of the delta ridge to the north is about 27 feet higher than the bottom of the lake. Natural overflow will not occur, therefore, until the lake has a maximum depth of nearly 30 feet and an area of nearly 1,000 square miles.

The lake receives practically all of its water from Kings, Kaweah, and Tule Rivers. The Kings River furnishes the largest quantity. During flood periods about half of the total flow below all diversions enters the lake. Under normal conditions all the water of the Tule River and nearly all of that of the Kaweah River is diverted for irrigation, and only a small quantity of water from these streams reaches the lake. The water from Kern River is stored in Kern Basin, except in years of great run-off. It is said that previous to 1906 no water had reached the lake from Kern River for 25 years. It thus appears that in years of great run-off, like 1906-7, there will always be a flow into the lake. Owing to variations in the overflow, therefore, and in evaporation, which amounts to about 4.5 feet a year, it is probable that the lake will continue to fluctuate very much as in the past, though possibly never reaching very high stages.

#### TRIBUTARIES OF THE SAN JOAQUIN RIVER.

All of the tributaries of the San Joaquin River rise in the high regions of the Southern Sierra and flow westward. Those which materially affect the flood situation in the floor of the valley take a course nearly parallel with the upper end of the trunk stream and join it at right angles at points below its elbow north of Mendota. Named in their order from south to north, they are the Merced, Tuolumne, Stanislaus, Calaveras, and Mokelumne Rivers. The Fresno and Cowchilla Rivers, while tributary to the San Joaquin, are of no importance so far as the flood situation of the San Joaquin Valley is concerned. The Fresno, however, has a fairly extensive watershed and, under the influence of heavy local rains, has been known to overflow a considerable area directly contiguous to its course; but its rise is practically coincident with the cause, making flood forecasts impracticable.

The Merced River drains an extensive section directly north of the upper end of the San Joaquin and joins the lower section of that stream at a point a few miles east of Newman. The drainage basin

of the Merced above the valley is quoted at 1,200 square miles. The most elevated region of its watershed is about 13,000 feet. The Yosemite Valley is wholly within the drainage basin of the Merced River.

A regular river and rain-fall station is maintained on the Merced at Merced Falls, 35 miles from the mouth of the river. The drainage basin above the station is about 1,000 square miles. The mean annual precipitation in this basin ranges from 10 to 15 inches in the valley to 20 or 25 inches in the foothills. In the higher regions it amounts to 60 inches or more, much of which is snow, which melts during the latter part of May or the first decade of June, often resulting in freshets in the lower reaches of the river. While the greatest flow of the Merced is in May or June, sometimes in July, should warm weather be delayed, this only takes place in years of normal or heavy snowfall in the mountains. Heavy, warm rains occasionally occur during the winter months, and in March, in which case floods result in some of the sections contiguous to the mouth of the river.

The Tuolumne River flows southwestward from the high mountains nearly parallel with the Merced whose watershed bounds it on the south. It drains about 1,500 square

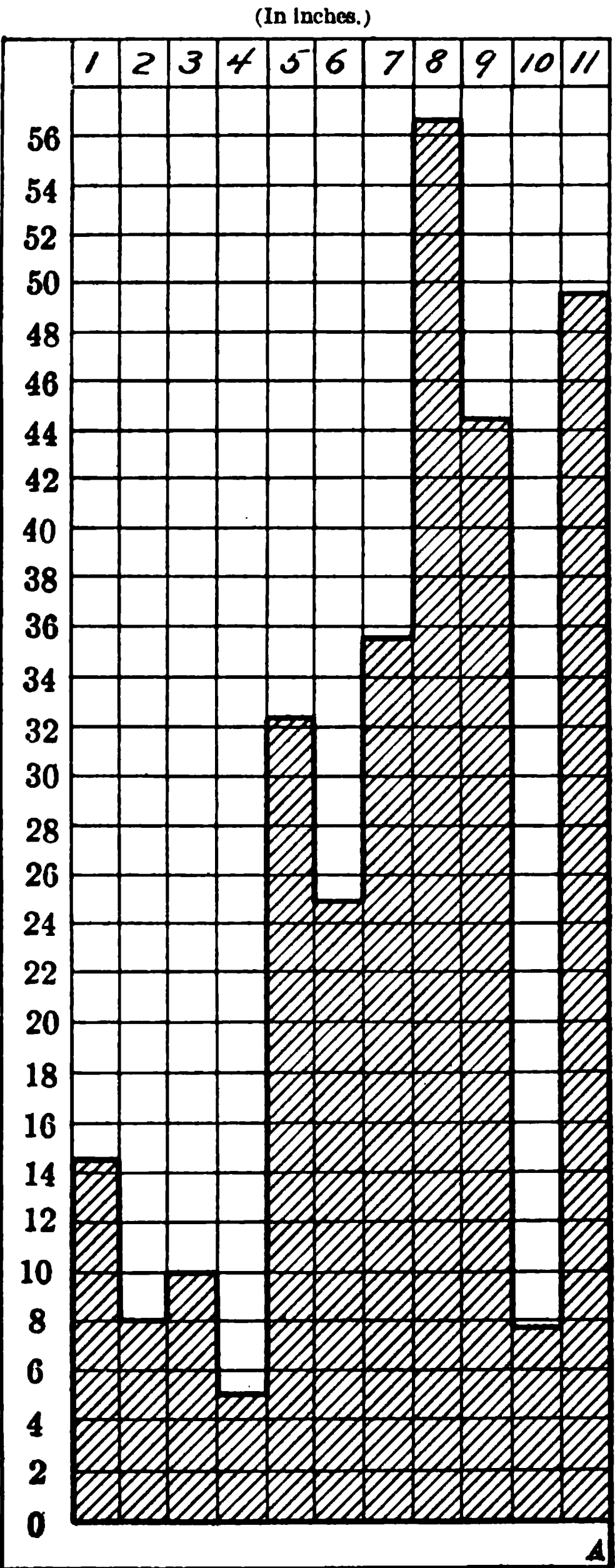


FIG. 15. Normal annual precipitation at 11 stations in the San Joaquin watershed. See page 56.

miles above Woods Creek, one of its most important tributaries. The highest point drained is about 13,000 feet on the North Slope of Mount Lyell. The mean annual precipitation in this watershed varies from about 10 inches in the valley to as much as 60 inches in the higher regions. It decreases rapidly as the floor of the valley is approached. Above the 5,000-foot level it is mostly all in the form of snow, which melts rapidly in the late spring and early summer and contributes to the usual June freshets in the lower San Joaquin Valley. Heavy rains are not uncommon during the winter months, or in March, in which case the river, which has a heavy fall, quickly responds and its flood wave hurries to the San Joaquin, which it joins a short distance west of the town of Modesto.

The stations and altitudes (see fig. 15) are as follows:

	Eleva- tion (feet).		Eleva- tion (feet).
1. Stockton.....	23	7. Sonora.....	1, 825
2. Los Banos.....	121	8. Summerdale.....	2, 270
3. Fresno.....	293	9. West Point.....	2, 326
4. Bakersfield.....	394	10. Kernville.....	2, 600
5. Mokelumne Hill.....	1, 550	11. Crockers.....	4, 947
6. Milo.....	1, 600		

The United States Weather Bureau maintains a regular river and rainfall station at Jacksonville, just below the mouth of Woods Creek, which enables it to make accurate flood forecasts for Modesto and the regions adjacent to the mouth of the river, where a large area is protected by levees. The average fall of the Tuolumne from Hetchy-Hetchy to La Grange, 18 miles below Jacksonville, is 51 feet per mile. Jacksonville is 64 miles from the mouth of the river, and it has been estimated that a flood wave of 25 feet at this station will reach the San Joaquin in 11 to 13 hours, thus giving ample time for an intelligent river forecast for all sections subject to overflow. The greatest and most rapid rise on record for the Tuolumne occurred at Jacksonville between the 29th and 30th of January, 1911, when the river rose from 4.6 to 26 feet in 24 hours. The last-named stage was augmented by another foot rise by 7 a. m., January 31, when the river attained a stage of 27 feet, the highest on record.

The Stanislaus River drains a narrow basin between the Tuolumne and Mokelumne watersheds. The greatest altitude drained is quoted as 11,000 feet. The mean annual precipitation in the watershed of the Stanislaus ranges from 12 to 15 inches in the valley to as much as 50 inches or more in the mountains, where it is mostly as snow. This stream usually carries an increased volume of water during the late spring and early summer, as a result of melting snow. but heavy rains in the foothill sections are not uncommon during

the winter months causing floods in its lower reaches. The Stanislaus empties into the San Joaquin about 5 miles below the town of Tuolumne. The Weather Bureau maintains a river and rainfall station on this stream at Melones, 64 miles from the mouth of the river. The drainage basin above the station is about 562 square miles. Owing to the great fall of this stream from its source to its mouth, which is quoted as 70 feet to the mile, high stages in its upper parts usually reach the San Joaquin in about 10 hours, and its flood waves pass down the main stream several hours in advance of those of the Tuolumne and Merced.

The Calaveras River drainage is between that of the Stanislaus and the Mokelumne basins. This stream has the most restricted watershed of any in the San Joaquin Valley north of Kings River, and probably the smallest annual runoff per square mile of any river tributary to the Great Valley, except the Tule, north of Tulare Lake. The highest point drained is between 4,000 and 5,000 feet. The river flows southwestward from the foothills to the little town of Bellota, where it is deflected into a narrow channel known as "Mormon Slough," which empties into Stockton Channel.

The mean annual precipitation in the Calaveras watershed varies from about 16 inches in the vicinity of Stockton to 35 or 40 inches in the higher regions. Some snow falls on the summit of its basin but not in sufficient quantities to materially affect its flow. In fact, this stream is rarely kept alive much later than the 1st of July, after which it is usually dry until the first rains of winter. During the winter months heavy rains sometimes occur and occasionally result in damaging floods in the regions contiguous to Stockton, Bellota, and Linden. Stockton itself, or the greater part thereof, has been rendered practically immune from the ordinary floods of the Calaveras by the construction of a canal which diverts the flood waters of Mormon Slough into the lower Calaveras River, proper, a short distance below Stockton, whence they are carried to the San Joaquin. The flooding of Stockton and the adjacent section in 1909, before the completion of the diverting canal, and the great flood of 1911, when thousands of acres east of Stockton were under water, resulted exclusively from the overflow of the Calaveras. (See fig. 15, "Annual precipitation in San Joaquin Watershed.")

Two river and rainfall stations are in operation on the Calaveras, one at Bellota on Mormon Slough, 17 miles east of Stockton, and one at Jenny Lind, 13 miles above the point where the river flows into the Slough; and a rainfall station is maintained at San Andreas, 26 miles above Jenny Lind. Although the average fall of the Calaveras is nearly 15 feet per mile, and the fall between Bellota and Stockton is about 5 feet per mile, the advance of flood waves has heretofore been greatly retarded by spreading in the vicinity of

Bellota and Linden. With prompt service from river and rainfall stations it is possible to make timely forecasts for the greater part of the area subject to overflow. In fact the Bureau has not yet failed to do this at any time since the establishment of the river service.

Heavy rains in the San Joaquin Valley are usually coextensive with the watersheds of the Upper San Joaquin, Merced, Tuolumne, Stanislaus, and Calaveras Rivers, and result in the passage of four well-defined flood waves down the San Joaquin River, south of Lathrop. The crest of that of the Upper San Joaquin, and the discharge of the North branch of Kings River, usually reach the flat country in the vicinity of Mendota and Firebaugh about the time that those of the Merced, Tuolumne, and Stanislaus reach the lower San Joaquin. Should heavy rains continue, even for a few hours after the above-named streams have attained flood stages, the capacity of the trunk stream becomes overtaxed, and all points subject to overflow between the mouth of the Tuolumne and that of the Calaveras are liable to inundation.

The Mokelumne River flows southwestward from the Sierras and empties into the San Joaquin at a point about 25 miles northwest of Stockton. The greatest elevation drained by this stream is about 10,000 feet. In addition to numerous lakes and small creeks that feed the Mokelumne it has an important tributary in the Cosumnes, which joins it near Thornton, about 6 miles from Walnut Grove on the Sacramento. At flood stage the Cosumnes has a greater discharge than the Mokelumne itself above the point where the two rivers meet. The Cosumnes has the greatest fall of any river in the Great Valley, and is quoted as something over 80 feet per mile. The mean annual precipitation in the Mokelumne-Cosumnes watershed varies from something less than 20 inches in the valley to as much as 60 inches in the high mountain ranges in Alpine and El Dorado Counties.

The Weather Bureau maintains two river and rainfall stations on the Mokelumne; one at Electra, 70 miles from its mouth and 55 miles from its junction with the Cosumnes, and one at Bensons Ferry, a short distance below the point where the two rivers meet. The drainage area above Electra is 537 square miles; that above Bensons Ferry is about 1,200 square miles.

Floods rarely, if ever, occur in the Mokelumne as a direct result of melting snow, but heavy, warm rains during the winter months are liable to cause floods over an extensive area of low country below the mouth of the Cosumnes. During all previous floods of which there is an authentic record, and especially those of 1904, 1907, and 1909, a large area of country in the neighborhoods of Bensons Ferry and Lodi has been flooded. During the 1904 flood many of the levees



of the lower Mokelumne were swept away by the waters of the Sacramento, which escaped through what is known as the "Edwards break" and swept southward along the lowlands lying east of and parallel with the Sacramento River. The Edwards break occurred on the 27th of February, 1904, and three or four days later between 40,000 and 50,000 acres were under water between the Sacramento and the Mokelumne Rivers, with an estimated loss of over \$1,000,000 in Sacramento and San Joaquin Counties. The loss, however, was greater in the last named county along the South Fork of the Mokelumne.

In the 1907 flood the Mokelumne overflowed its banks above Lodi and Woodbridge, inundating many thousands of acres of land. In 1907 the floods of the Mokelumne were greatly augmented by the waters of the flooded Sacramento, which escaped eastward through a break in the levees near Courtland. It was the added water of the Sacramento River which resulted in the flooding of the Pierson District in 1909.

During the 1909 floods, while the Mokelumne was high, there was only one small break in its levees, which resulted in the inundation of perhaps a thousand acres.

The highest water on record, however, in the Mokelumne occurred in 1911, but all levees which had been strengthened held and there was little damage.

For much of the information regarding the Mokelumne floods the writer is indebted to Mr. Edward H. Barber, of Thornton, Cal.

#### FLOODS IN THE SACRAMENTO RIVER.

River readings were made at various points in the Sacramento River during the early days, but, until the river service was established by the Weather Bureau, the readings were in most cases indifferently made, and even the best of records were made without regard to any particular datum. The height of flood waters in former days have, however, at some points on the river, been fairly well established by landmarks, which furnish a basis of comparison with stages that have been recorded since the establishment of the service by the Government. Of course, conditions in the old days were vastly different from those that prevail at the present time. Before the settlement of the valley the river during high water roamed at will after it had emerged from its rocky canyons. Protected from the lowlands on either side only by its low banks, which sloped back into the floor of the valley, the river spread over large areas at stages that in these days would be called only moderate. It is believed that many of the "floods" that are associated with the early history of the Sacramento Valley would now pass unnoticed to the bay between levees.

There is, however, ample proof of the fact that there have been some high stages in the Sacramento River in the old days that would probably have been difficult to control even with the levee systems that now protect many of the agricultural districts and some of the smaller towns of the valley.

Regarding the various floods of the Sacramento and American Rivers in the city of Sacramento and its vicinity, history begins with that of 1850-51. Tradition, however, recounts an inundation in 1805, when it is said the entire Sacramento Valley was covered with water, except Marysville Buttes. This tradition was handed down by the Indians and at the time of the first white settlers in this section stories of the "great waters" were still extant.

The History of Sacramento County, by Thompson and West, published in 1880, contains some interesting accounts of the floods in the vicinity of Sacramento from 1850 to 1878. According to this history the flood of 1850 is the first of which there is an authentic record, and it refers to this flood as follows:

From January 9 to 17, 1850, the entire city of Sacramento was flooded.

In this connection it tells of heavy damage and some loss of life. Of course, the city at that time occupied only a small area, and while the damage was, no doubt, relatively heavy, the probability is that there was little to lose. That this flood was of some intensity is proven by the amount of rain that fell during December, 1849, and January, 1850. It was the flood of 1850 that first suggested the necessity of building levees around the city, and the introduction of this method of protection dates from that year.

The following is taken from the history of Sacramento County:

On March 7, 1852, another flood occurred at Sacramento, which leveled the most of the levees that had been built for the protection of the city.

During this flood, which must have come from the American River, historians of this section record the destruction of many bridges on this stream, especially those which spanned the South and Middle Forks.

On January 1, 1853, the city of Sacramento was again flooded, the water, according to history, rising to 22 feet above low-water mark. Little damage resulted from this flood, which seems to have subsided quickly, offering evidence of the fact that it came in from the American River.

From 1854 to 1860, inclusive, there are no records of floods in any part of the Sacramento watershed, and the record of precipitation during this period shows no heavy rainfall.

The history previously referred to states that on March 28, 1861, another flood of brief duration occurred on the American River, during which the river was 20 feet above low-water mark. On

December 9, 1861, the American is reported to have risen to 22.7 feet above the low-water mark, resulting in considerable loss.

The greatest and most disastrous flood of which there is any remembrance, and one that seems to have been general throughout the Great Valley, north of Kings River, occurred between January 9 and 12, 1862. The highest water at Sacramento during this flood has been quoted as 24 feet above low water. It has been stated that the American rose 60 feet above low-water mark, but the point

FIG. 44.—High water near Folsom in 1862.

where the measurement was made is not stated. The probability is that the American has been greatly overestimated and the Sacramento has been quoted too low.

According to measurements made in October, 1912, from the attested high-water mark of the 1862 flood made on an old stone stable, near where the Stockton and Coover mill stood on the left bank of the American River a mile and a half above Folsom, the American River at Folsom during that flood would have registered 38.3 feet on the present gage, or 11.5 feet above the 1907 flood.



Judging from all accounts of the 1862 flood it must have been the combined output of the American, Feather, and Yuba Rivers.

The rainfall of December, 1861, and January, 1862, in the vicinity of Sacramento aggregated 23.68 inches, 15.04 inches of which fell in the last-named month. As a result of this unusually heavy rainfall, which was undoubtedly coextensive with the entire Sacramento as well as the San Joaquin watershed, the American River from Folsom to Sacramento City was kept at flood stage until the approach of the Feather-Yuba and upper Sacramento discharge, a condition that had probably never before occurred in this section during its occupation by white settlers. All settlements in both valleys suffered greatly during the great flood of 1862, especially the city of Sacramento, the levee system of which was entirely leveled.

There were three floods in the upper reaches of the Sacramento during the winter of 1861-62. According to Capt. Lee, of Tehama, Cal., who has been connected with the river in various capacities for the past 60 years, and who is still enjoying life at the age of 86 years, the first flood occurred on December 9, 1861, when the river was higher than it had been for many years at all points between Tehama and Red Bluff. According to Capt. Lee, the water was over a foot deep in the streets of Tehama and many thousands of dollars worth of stock was drowned in the vicinity of that town. The second flood occurred on the 29th of December, 1861, following several days of unusually heavy rainfall. Cottonwood Creek was higher than was ever before known; Ludwigs Bridge, that spanned this stream, was carried away. This flood overtopped the banks in the vicinity of Red Bluff and completely inundated Tehama and other settlements along the Sacramento River. The third flood occurred on January 23, 1862, the water reaching the 29-foot mark on the Red Bluff river gage and flooding the warehouse on the east side of the river.

The historians of the Sacramento Valley agree that there were no floods of any importance from January, 1862, to February, 1878, notwithstanding the fact that some heavy rains fell during this interval, notably, November and December, 1864, January, 1866; December, 1867; January, 1868; December, 1871; and January, 1875.

From February 1 to 20, 1878, there were several floods in the Sacramento and American Rivers in the vicinity of Sacramento. On the first-named date the river rose higher than was ever before recorded, 26 feet above low-water mark. Some damage resulted from this flood, caused by the breaking of the levees near Lovdal's ranch, between the city of Sacramento and Sutterville.

The city of Sacramento has remained secure since 1878, notwithstanding the fact that the high stages previously recorded have been exceeded a number of times, notably, as follows: February 4,

1881, 26.6 feet; December 12, 1889, 27 feet; March 4, 1891, 27.6 feet; May 30, 1892, 27.2 feet; December 27, 1892, 28.6 feet; March 22, 1893, 26.5 feet; January 29, 1896, 26.6 feet; February 25, 1901, 28.2 feet; March 1, 1902, 28.2 feet; March 4, 1903, 27.6 feet; February 27, 1904, 26.1 feet; February 7, 1907, 27.2 feet; and January 17, 1909, 29.6 feet, the highest ever recorded.

While, as has been stated, the city of Sacramento itself has not been flooded in recent years, all of the high stages quoted above have resulted more or less seriously at many points up the river, especially in cases where vulnerable levees offered inadequate protection to lands in process of reclamation. For instance, the flood of 1881, is still remembered in the vicinity of Red Bluff and Tehama, where a large area of country was under water, causing heavy damage—loss of stock, destruction of bridges, etc. This flood was the result of heavy rainfall that was, for the most part, confined to the northern end of the valley, over 7 inches of rain having been recorded at Red Bluff during the three days ending January 30, 1881, and torrential rains, according to authentic reports, at points contiguous to the junction of the Sacramento and Pit Rivers.

The two most notable floods of the Sacramento and San Joaquin Valleys, from a pecuniary standpoint, were those of March, 1907, and January, 1909. It is thought that these floods were equally as widespread as was that of 1862, and the losses were, no doubt, far in excess.

In 1907 the land thought to be protected and that under process of reclamation aggregated a greater acreage than at any previous time in the history of the Great Valley. The same may be said of the flood of 1909, as the flood of this year occurred about the time when new levees had replaced those leveled two years previous, and many new reclamation districts besides. During both of these floods many levees were either badly damaged or totally destroyed, large areas rendered useless for immediate cultivation, bridges, both railroad and county, swept away, and many miles of county roads and railroad tracks rendered impassable.

The floods of 1907 and 1909 in the Sacramento and San Joaquin Valleys, and those of 1911 in the Lower San Joaquin Valley are the only inundations of which there is a complete record at all strategic points on the two trunk streams and their main tributaries.

#### THE FLOODS OF 1907.

The great floods that prevailed in the rivers of the Sacramento and San Joaquin Valleys during March, 1907, were, of course, the direct results of heavy, warm rains and melting snows that immediately preceded them.

## 64 FLOODS OF SACRAMENTO AND SAN JOAQUIN WATERSHEDS.

*Table of daily precipitation at selected stations in the Sacramento and San Joaquin watersheds during March, 1907.*

[In this connection see hydrographs, figs. 23 to 27, inclusive, for this period.]

Date.	Alturas.	Sisson.	Ken- nett.	Duns- muir.	Delta.	Shasta.	Red- ding.	Red Bluff.	Nim- shew.	Quincy
Elevation, feet.....	4,460	3,555	616	2,285	1,138	1,049	552	307	2,500	3,400
Mar. 8.....	0.28	0.00	0.00	0.20	0.05	0.13	0.01	0.04	0.00	0.00
Mar. 9.....	.05	.45	.50	.66	1.10	.33	.67	.69	1.49	.60
Mar. 10.....	.05	.66	.0	.30	1.90	1.14	.49	.21	.33	.40
Mar. 11.....	.25	.00	.00	2.53	.90	.16	.18	.06	1.45	.60
Mar. 12.....	.00	.00	.00	.00	.10	.00	.00	.00	.00	.20
Mar. 13.....	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Mar. 14.....	.00	.00	.56	.00	.00	.00	.00	.00	.00	.00
Mar. 15.....	.00	.00	.00	.00	.00	.00	.00	.69	.00	.00
Mar. 16.....	.08	.00	.00	.00	.00	.38	.38	.65	1.40	.70
Mar. 17.....	.55	.00	.00	2.00	1.10	1.54	1.36	.62	5.54	5.30
Mar. 18.....	.75	3.55	.00	2.87	3.50	2.25	.88	.28	4.00	6.50
Mar. 19.....	.14	1.27	.54	2.72	3.50	1.03	.11	.00	3.02	4.40
Mar. 20.....	.15	2.25	2.44	2.00	3.10	.17	.07	.01	1.17	1.75
Mar. 21.....	.01	.60	2.00	.72	.80	.51	.23	.75	.43	.50
Mar. 22.....	.05	.60	1.56	.60	1.00	2.17	.19	.23	.75	.60
Mar. 23.....	.60	2.00	.82	.80	2.50	1.93	1.12	.05	2.00	3.60
Mar. 24.....	.05	.20	.82	.40	2.00	.62	.11	.06	.38	1.30
Mar. 25.....	.15	.40	.08	1.20	.10	.51	.09	.89	.62	1.40
Sum.....	3.16	12.0	9.32	18.8	21.6	12.9	5.89	5.23	22.6	27.8

Date.	Chico.	Fruto.	Colusa.	Oro- ville.	Will- ows.	Nevada City.	Au- burn.	Fol- som.	Sacra- mento.	George- town.
Elevation, feet.....	189	624	60	147	136	2,580	1,360	111	71	2,650
Mar. 8.....	0.00	0.00	0.36	0.00	0.00	0.08	0.46	0.00	0.12	0.00
Mar. 9.....	.93	.23	.50	.30	.42	1.45	.00	.24	.40	.50
Mar. 10.....	.18	.36	.10	.86	.18	.51	2.35	.98	.15	2.31
Mar. 11.....	.25	.00	.00	.43	.06	.96	.32	.52	.06	.65
Mar. 12.....	.02	.00	.00	.22	.00	.15	.00	.20	.00	.75
Mar. 13.....	.00	.00	.00	.00	.00	.00	.00	.00	.00	.40
Mar. 14.....	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.20
Mar. 15.....	.00	.00	.26	.33	.00	.00	.00	.00	.04	.40
Mar. 16.....	.81	.22	.78	2.35	.51	.91	.16	.26	1.15	.30
Mar. 17.....	1.58	.45	.14	1.10	.70	2.47	2.08	1.42	.42	3.54
Mar. 18.....	.73	.40	.46	1.44	.13	3.34	.39	.10	1.74	1.08
Mar. 19.....	.36	.30	.12	.52	.05	3.63	3.11	2.08	.56	4.90
Mar. 20.....	.35	.25	.00	.08	.01	1.50	.88	.60	.06	1.48
Mar. 21.....	.22	.00	.22	.30	.15	.41	.36	.26	.15	.76
Mar. 22.....	.18	.00	1.02	1.32	.01	.58	.44	.26	.05	.91
Mar. 23.....	1.31	1.20	.20	.48	.78	3.43	.83	.68	1.46	1.78
Mar. 24.....	.06	.00	.08	.22	.15	.98	.00	1.28	.25	2.55
Mar. 25.....	.00	.30	.00	.11	.00	.90	2.94	.62	.01	1.85
Sum.....	6.98	3.71	4.24	10.1	3.15	21.3	14.3	9.50	6.62	25.4

*Daily precipitation at selected stations in the San Joaquin watershed from Mar. 4 to Mar. 23, 1907.*

Date.	Sanger.	Fire- baugh.	Merced Falls.	Friant.	Yosem- ite.	Jack- son- ville.	Me- lones.	La- throp.	Elec- tra.	Jenny Lind.
Elevation, feet.....	371	154	321	355	3,945	602	750	19	670	.....
Mar. 4.....	0.35	0.43	0.41	0.34	0.61	0.50	1.30	0.00	0.44	0.00
Mar. 5.....	.32	.14	.20	.44	1.88	.41	.24	.44	.42	.32
Mar. 6.....	.28	.05	.30	.38	.25	.30	.14	.00	.18	.26
Mar. 7.....	.00	.00	.00	.00	.05	.26	.26	.00	.04	.22
Mar. 8.....	.04	.00	.00	.00	.10	.28	.00	.00	.00	.00
Mar. 9.....	.00	.00	.00	.00	.01	1.46	.00	.00	.00	.00
Mar. 10.....	.00	.00	.33	.38	2.15	1.52	1.98	.60	2.20	.10
Mar. 11.....	.56	.68	.60	.74	.92	.28	1.92	.06	.86	1.60
Mar. 12.....	.19	.10	.10	.12	.38	.00	.64	.10	.86	.45
Mar. 13.....	.00	.00	.00	.00	.00	.00	.00	.00	.16	.50
Mar. 14.....	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Mar. 15.....	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Mar. 16.....	.00	.00	.00	.00	1.40	.00	.00	.00	.00	.19
Mar. 17.....	.29	.08	.20	.40	2.61	1.30	1.88	.84	1.66	.70
Mar. 18.....	.00	.00	.00	.00	2.02	.01	.06	.00	.26	.06
Mar. 19.....	.10	.03	1.10	.28	1.85	2.48	2.06	.80	4.56	2.00
Mar. 20.....	.19	.00	.00	.02	1.15	.08	.00	.00	.44	.10
Mar. 21.....	.16	.41	.47	.00	.65	.90	1.04	.00	1.00	.40
Mar. 22.....	.16	.12	.32	.36	.85	.62	1.84	.48	.64	.35
Mar. 23.....	.38	.00	1.13	.06	.60	.00	.00	.00	.24	.46
Sum.....	3.02	2.04	5.16	3.52	17.5	10.4	13.4	3.32	14.0	8.60

*Hydrographs, Sacramento River system, March, 1907.*

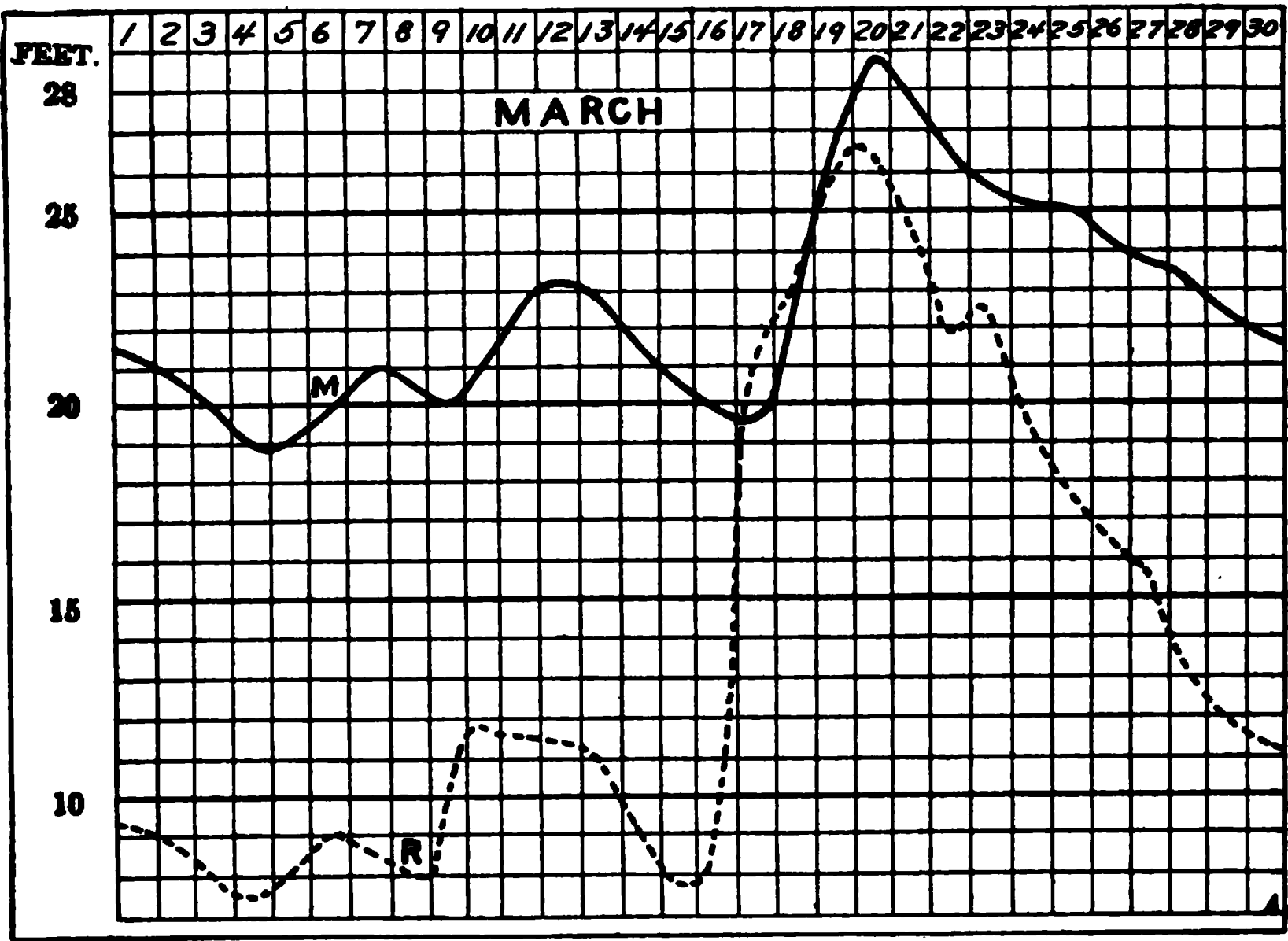


FIG. 23.—Hydrographs, March, 1907. M, Colusa; R, Red Bluff.

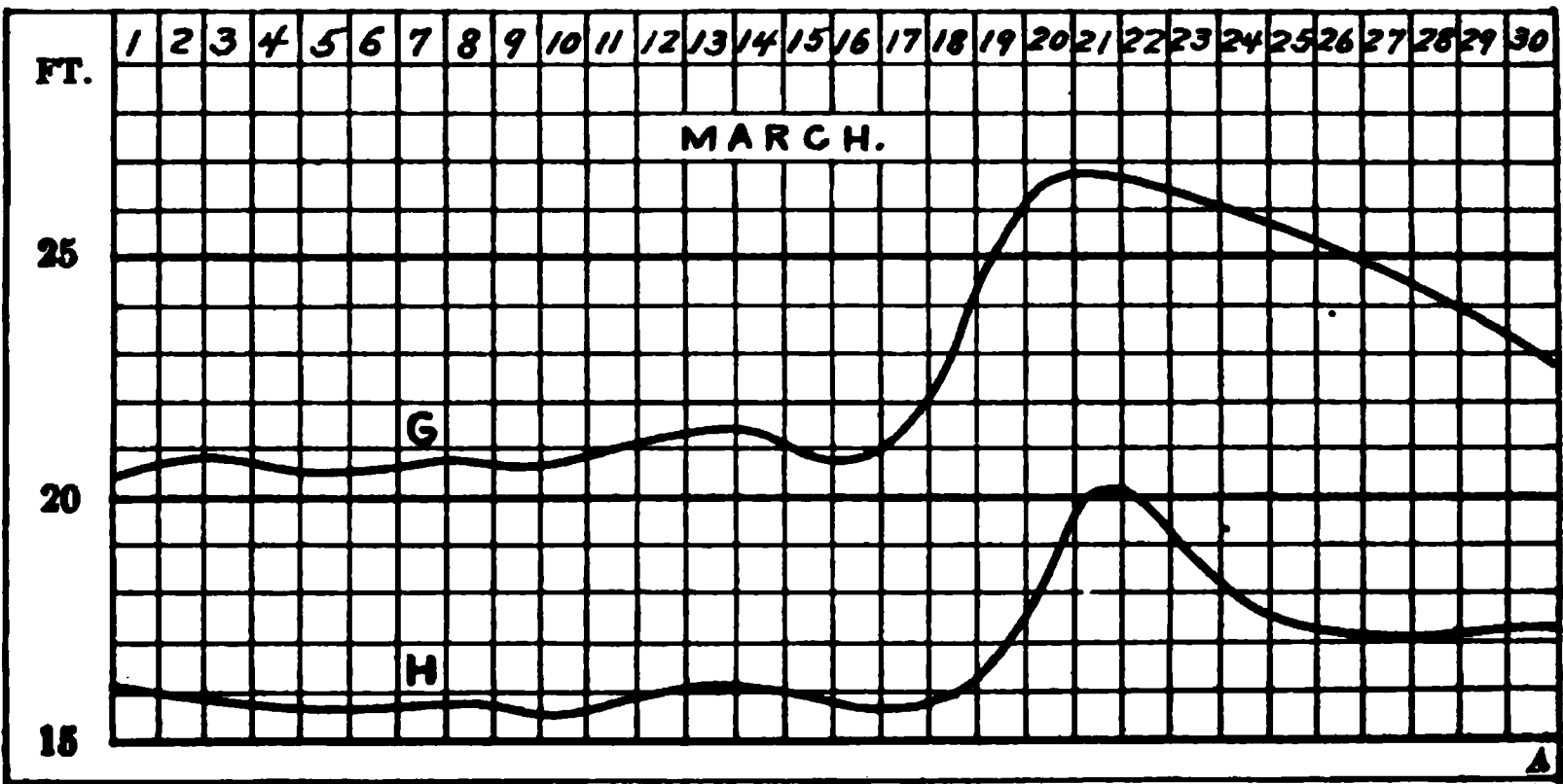


FIG. 24.—Hydrographs. G, Sacramento; H, Knights Landing.

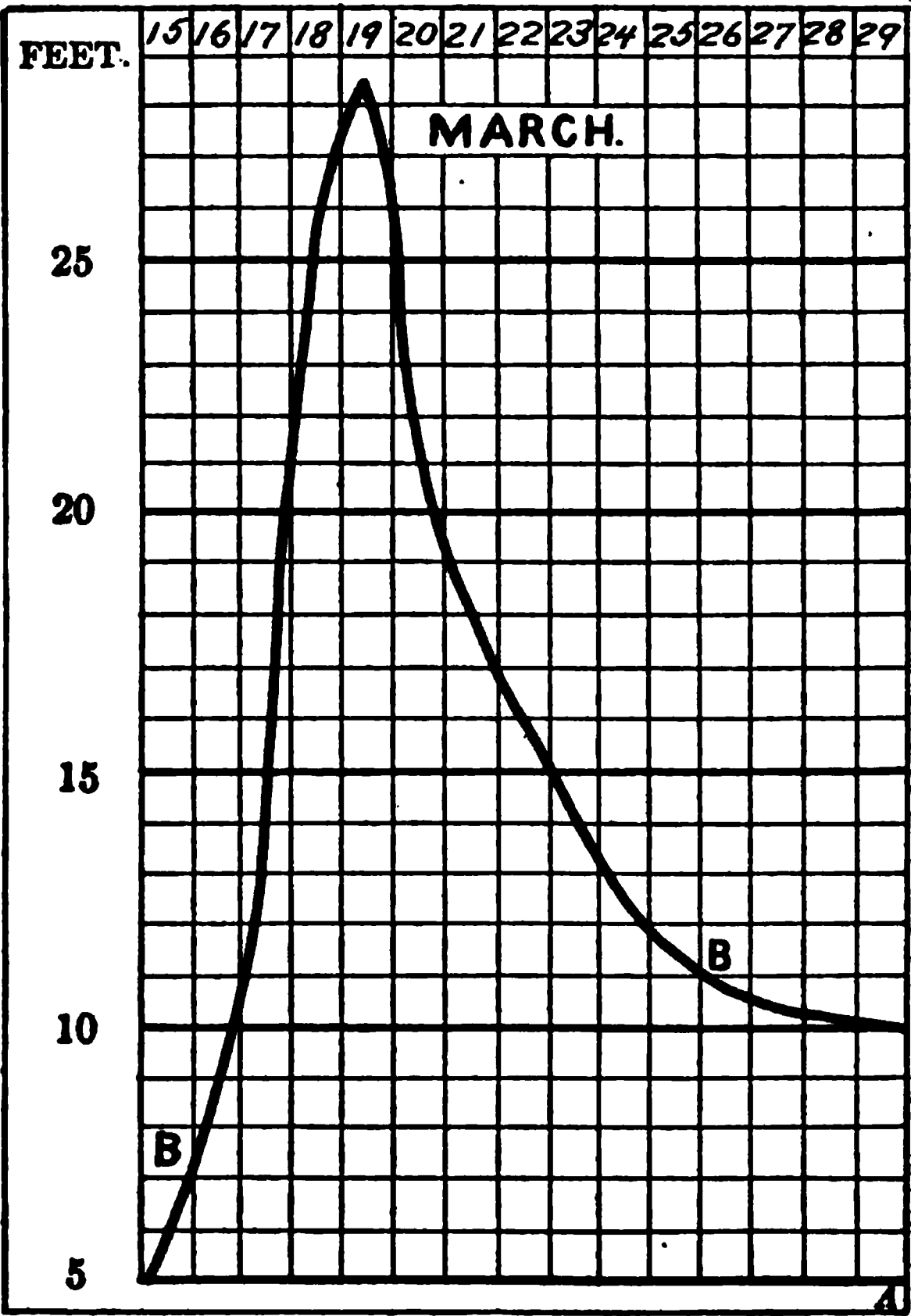


FIG. 25.—Oroville on Feather, March, 1907.

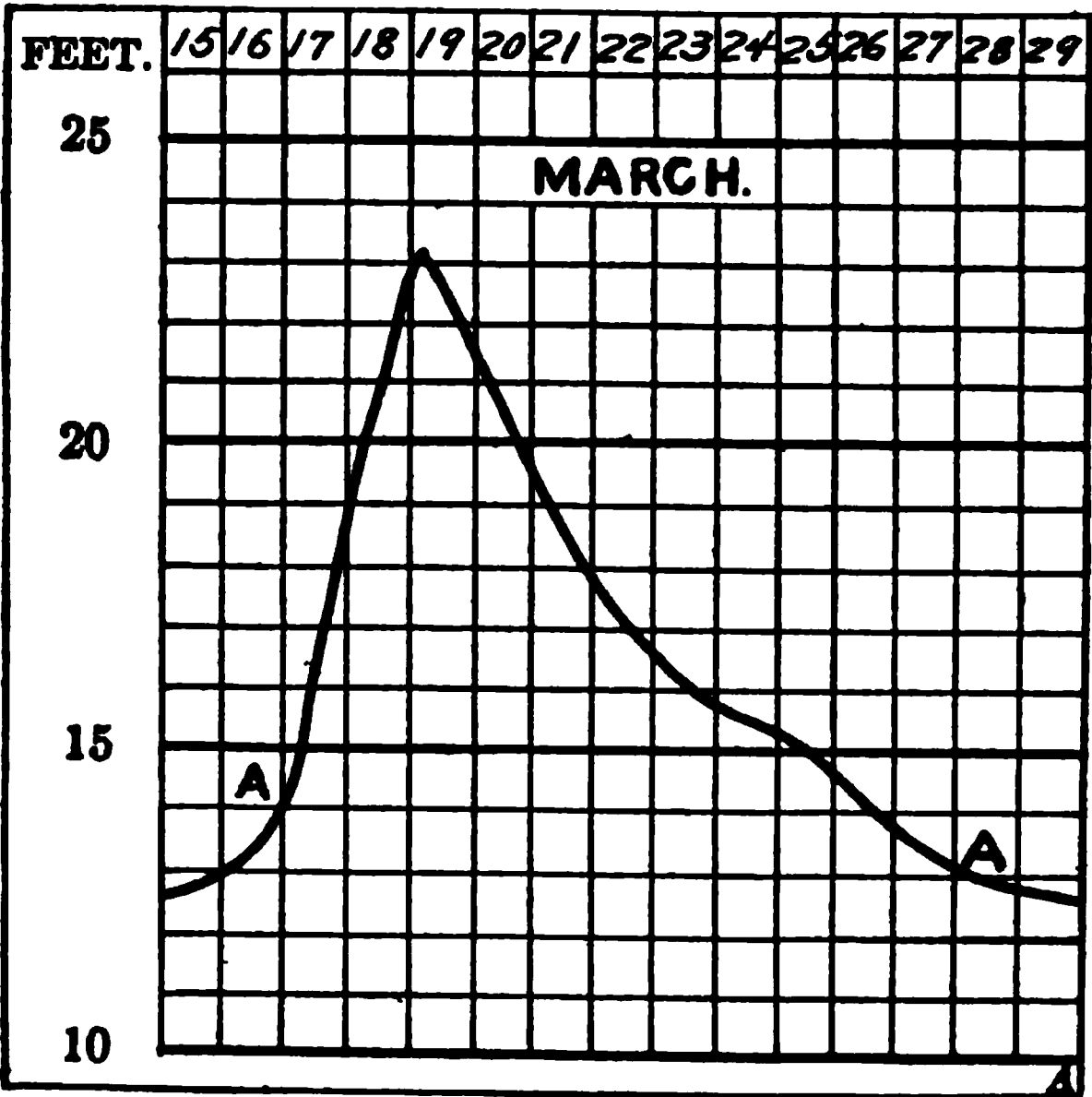


FIG. 26.—Marysville on Yuba, March, 1907.

*Hydrographs, Sacramento River system, March, 1907—Continued.*

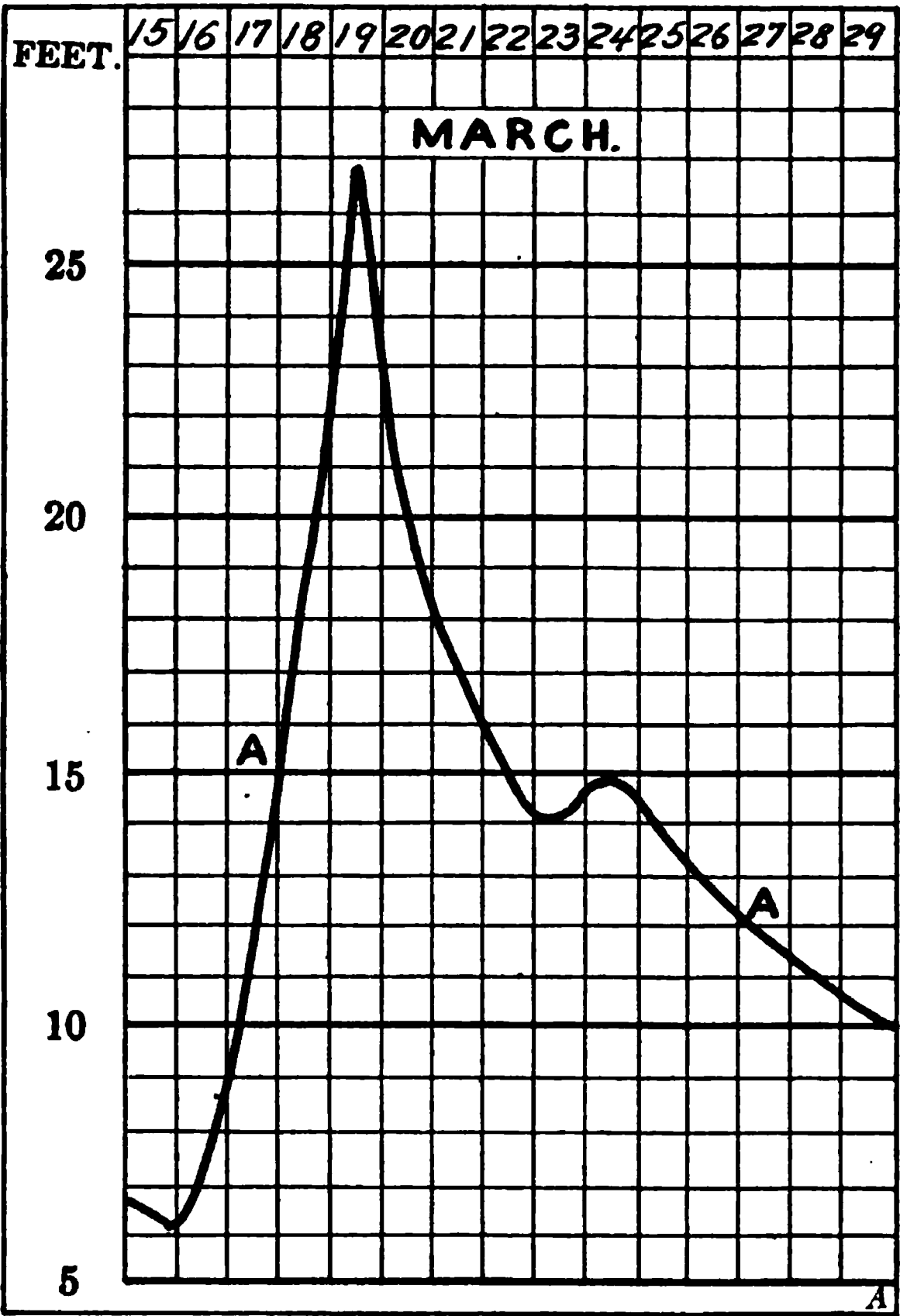


FIG. 27.—Folsom City on American, March, 1907.

Conditions, however, during January and February of that year were largely responsible for the intensity of those in the watershed of the Sacramento. During the first days of January and the first decade of February the occurrence of heavy rains in the headwaters of the Sacramento drainage basin caused rapid rises in all streams, and, in some cases, floods and freshets. There were marked and dangerous rises at Folsom, on the American, on February 2, and at Marysville, on the Yuba, on the 3d, where stages of 21.2 and 22.2 feet, respectively, were recorded. From February 4 to 11, inclusive, high stages were also general in parts of the Sacramento River.

Before the rivers of the Sacramento watershed had recovered from the rains and melting snows of February, and while all flood basins on both sides of the Sacramento were practically full, another period of precipitation occurred between March 4 and 11. This condition resulted in raising the rivers to a point much beyond the stages usually maintained at this time of the year. From March 16 to 20, inclusive, there was another period of precipitation that was coextensive with the entire northern half of the State. At the same time temperatures were much above the seasonal normal in the high foothills and on the flanks of the mountains, which were thickly covered with the accumulated snows of the two preceding months. The effects of the heavy, warm rains and melting snows were almost immediate, and all the main rivers quickly responded to the increased run-off of the mountain feeders. At Kennett, on the Upper Sacramento, the river rose from 6.3 on the 17th to 18 feet on the 18th, and to 25 and 33.2 feet, respectively, on the two succeeding days. At Red Bluff the river rose from 7.9 to 20.7 feet between the 16th and 17th. On the 18th, 19th, and 20th, while the flood waters of the Upper Sacramento and Pitt Rivers were passing, stages of 22.8, 26, and 26.8 feet, respectively, were recorded at Red Bluff. At Colusa the river began rising rapidly during the night of the 17th, and by the morning of the 18th there was a gage reading of 22.7 feet, followed on the 19th and 20th by stages of 26 and 26.8 feet, respectively. The river rose slowly at Knights Landing, as the numerous breaks above tended to flatten out the flood wave before reaching that point. The river was high, however, and continued above the flood stage from the 20th to 24th, inclusive. By the morning of the 17th the river at Sacramento City had already become swollen as a result of the output of the American. On this date a gage reading of 20.9 feet was observed, after which the river rose gradually, averaging about 1 foot per day until the 20th, when it culminated in a stage of 26.9 feet. The breaking of the levees at many points above and below Sacramento checked a further rise at this point, but the river remained above the 26-foot stage for several days. The effects of the Sacra-



mento River flood were first felt at Rio Vista on about the 21st, after which the river at that point rose rapidly until the 24th, when it culminated in a stage of 17 feet, but a high stage was maintained for several days, due to the output of Yolo Basin through the sloughs that drain this basin into the Sacramento River.

The American at Folsom began rising on the night of the 16th, and by the morning of the 17th had risen from 6.2 to 12 feet. On the 18th it had risen to 18.6 feet, and by 7 a. m. of the 19th had reached the unusually high stage of 26.8, the highest ever recorded, except during the flood of 1862.

Coincident with the rise of the American, the Feather and Yuba Rivers rose rapidly. At Marysville, on the Yuba, the river rose from 14.1 to 20.1 feet from the 17th to 18th, and by the morning of the 19th had reached a stage of 23.3 feet, the highest observed.

At Oroville, on the Feather, the river rose from 5.1 to 11.6 feet during the 24 hours ending at 7 a. m. of the 17th. On the morning of the 18th it had risen to 23.6, and at 7 a. m. of the 19th the gage showed 28.2 feet, the crest of the flood at that point. As has been stated in another part of this paper, the flood waters of the Feather escaped through breaks in the levees at Hamilton Bend and rushed westward across country between Biggs and Gridley, thence through the lowlands north of Marysville Buttes and into the Sacramento River by way of Butte Slough.

While the floods were raging in the Sacramento Valley, like conditions were occurring in all sections of the San Joaquin north of the Tuolumne. The Tuolumne at Jacksonville reached a stage of 24 feet on the 19th, and a high stage was maintained on this stream from the mouth of Woods Creek to its mouth until the 21st, after which it fell sharply. The Stanislaus rose briskly from the 16th to the 21st, culminating at a stage of 12.2 feet, the highest on record. It remained at a high stage until the 26th. The Calaveras rose from 4.3 to 13 feet between 7 a. m. of the 16th and the corresponding hour of the 17th, and rushed into Mormon Slough at the rate of some 10 miles an hour and thence overflowing a large area of country. The Mokelumne rose from 8 to 13 feet during the 24 hours ending at 7 a. m. of the 19th. Below Bensons Ferry the flood waters of this stream were reenforced by a heavy swell from the Cosumnes. The combined run-off of the two rivers resulted in flooding something over 15,000 acres of land above Lodi. While the Mokelumne flood was at its worst, conditions were intensified by the breaking of the east side Sacramento levees near Courtland, through which the Sacramento River flood waters rushed into the lower Mokelumne Basin.

The San Joaquin River itself was at or above the flood stage from Mendota to the mouth of the river from the 19th to near the close



of the month; this was especially so below Lathrop, where the highest stage on record, 19.2 feet, was recorded on the 20th. From about the 21st to the 28th the greatest damage was done in the delta lands of both trunk streams. (See list of islands and other tracts that were flooded, p. 91.)

FLOODS IN THE SACRAMENTO AND SAN JOAQUIN VALLEYS, 1909.

There were a series of floods in the central valleys of California from January 14 to 25, inclusive, and during the first decade of February, 1909. Those during the first-named period equaled in intensity the floods of 1907.

The first dangerous condition noted in connection with the 1909 floods was the heavy rainfall throughout the San Joaquin Valley on the 13th of January, and especially in the headwaters of the Calaveras River.

Table of daily precipitation at selected stations in the Sacramento watershed from Jan. 1 to 31, 1909.

[See hydrographs, figs. 28 to 40, for this period.]

Date.	Alturas.	Sisson.	Ken- nett.	Duns- muir.	Shasta.	Red- ding.	Red Bluff.	Quincy.	Chico.
Elevation.....feet..	4,460	3,555	616	2,285	1,049	552	307	3,400	189
Jan. 1.....	0.01	1.25	1.22	1.74	0.84	1.25	1.04	1.02	0.90
Jan. 2.....	.05	1.24	1.74	1.55	.93	.85	.17	2.43	.79
Jan. 3.....	.08	.00	3.20	1.96	.48	.39	.08	1.37	.82
Jan. 4.....	.00	.90	.04	.16	.38	.23	.73	.00	.08
Jan. 5.....	.36	1.19	1.20	1.14	2.32	2.24	2.00	2.58	1.60
Jan. 6.....	.18	.89	2.90	2.05	2.04	1.53	.00	1.35	1.07
Jan. 7.....	.30	1.86	3.10	2.02	3.87	1.07	.71	1.96	.32
Jan. 8.....	.60	.15	3.04	2.64	2.68	2.43	.34	3.10	1.25
Jan. 9.....	.70	.00	1.24	.63	.08	.00	.00	.54	.00
Jan. 10.....	.00	.00	.00	.00	.54	.00	.00	.00	.00
Jan. 11.....	.00	.00	.00	.00	.67	.00	.00	.00	.00
Jan. 12.....	.00	.02	.00	.00	.34	.11	.29	.10	.04
Jan. 13.....	.11	.62	.50	.50	1.40	.73	.23	1.48	.43
Jan. 14.....	.69	.65	3.00	1.84	1.87	1.65	1.42	3.20	.28
Jan. 15.....	.17	1.22	2.68	1.56	.91	2.11	1.36	2.77	1.12
Jan. 16.....	.17	.31	8.90	3.00	.71	.51	.10	1.90	.44
Jan. 17.....	.30	.08	.54	.80	2.04	.94	.06	.35	.15
Jan. 18.....	.07	.33	1.04	.49	1.30	.04	.02	.17	.10
Jan. 19.....	.04	1.28	.90	1.00	2.13	.93	.04	1.10	.50
Jan. 20.....	.05	2.25	2.42	2.49	2.94	.77	.69	2.45	.70
Jan. 21.....	.40	.65	.60	2.45	1.60	.22	.12	1.77	.46
Jan. 22.....	.17	.10	1.10	.48	1.17	.07	.04	.81	.10
Jan. 23.....	.00	.60	.06	.15	.97	.17	.08	1.09	.00
Jan. 24.....	.00	2.40	.50	1.10	2.28	3.45	1.43	.80	.75
Jan. 25.....	.01	.60	.50	1.30	.08	1.20	1.49	.83	.56
Jan. 26.....	.00	.00	3.10	.30	.15	.76	.47	.45	.80
Jan. 27.....	.01	.00	.30	.00	.00	.00	.00	.00	.05
Jan. 28.....	.00	.00	.00	.00	.00	.00	.00	.05	.00
Jan. 29.....	.00	.00	.00	.00	.68	.00	.00	.00	.00
Jan. 30.....	.00	1.30	.86	.30	.18	.58	.37	.50	.89
Jan. 31.....	.00	.83	4.00	.95	.38	.05	.14	1.00	.10
Sum.....	4.47	20.72	54.08	32.60	35.96	24.28	13.42	35.17	14.38

FLOODS OF SACRAMENTO AND SAN JOAQUIN WATERSHEDS. 71

Table of daily precipitation at selected stations in the Sacramento watershed from Jan. 1 to 31, 1909—Continued.

Date.	Fruto.	Colusa.	Oroville.	Willows.	Nevada City.	Auburn.	Folsom.	Sacramento.	Georgetown.
Elevation.....feet..	624	60	147	136	2,580	1,360	111	71	2,650
Jan. 1.....	0.90	0.16	0.54	0.71	0.80	0.42	0.44	0.39	0.90
Jan. 2.....	.33	.52	1.00	.12	.55	.20	.00	.28	.09
Jan. 3.....	.60	.00	1.26	.48	1.57	.62	.44	.05	.91
Jan. 4.....	.00	.40	.00	.08	.02	.00	.00	.21	.00
Jan. 5.....	.70	1.04	.68	1.10	.97	.41	.28	.34	.62
Jan. 6.....	1.05	.06	1.54	.74	1.79	1.45	.28	.35	1.87
Jan. 7.....	.00	.62	.06	.13	1.02	.23	.20	.06	.50
Jan. 8.....	.50	.04	1.40	.65	3.45	1.28	.92	1.05	2.40
Jan. 9.....	.20	.00	.10	.05	1.10	1.59	.98	.06	3.28
Jan. 10.....	.00	.00	.00	.00	.00	.00	.00	.00	.10
Jan. 11.....	.00	.06	.00	.00	.06	.00	.00	.04	.00
Jan. 12.....	.00	.22	.01	.13	.19	.18	.00	.65	.26
Jan. 13.....	.20	.18	.76	.16	2.92	2.40	1.34	.37	4.12
Jan. 14.....	.20	.68	.58	.28	4.48	2.95	.94	1.28	6.05
Jan. 15.....	.40	.50	.70	.74	3.26	3.20	2.10	1.03	5.56
Jan. 16.....	.80	.00	1.45	.70	1.62	2.00	1.60	.32	2.94
Jan. 17.....	.00	.04	.02	.00	.31	.00	.00	.12	.28
Jan. 18.....	.00	.06	.40	.00	.49	.70	.30	.00	.84
Jan. 19.....	.00	.12	.24	.17	.52	.08	.00	.29	.04
Jan. 20.....	.20	.58	.48	.51	2.31	1.20	.58	1.20	1.62
Jan. 21.....	.65	.16	.85	.30	1.68	1.28	1.28	.41	2.70
Jan. 22.....	.15	.00	.34	.08	.50	1.68	.32	.15	.69
Jan. 23.....	.00	.06	.01	.01	.38	.29	.12	.00	.61
Jan. 24.....	.30	.52	.00	.76	.18	.00	.02	.44	.26
Jan. 25.....	.65	.68	.34	.21	.64	.42	.44	.12	.60
Jan. 26.....	3.30	.18	.42	.87	.09	.08	.10	.12	.04
Jan. 27.....	.10	.00	.08	.08	.13	.42	.22	.05	.35
Jan. 28.....	.20	.00	.01	.02	.01	.00	.00	.00	.02
Jan. 29.....	.00	.14	.00	.00	.00	.00	.00	.00	.00
Jan. 30.....	.30	.24	.00	.27	.81	.00	.00	.27	.00
Jan. 31.....	.00	.00	.00	.02	.01	.00	.48	.00	.71
Sum.....	11.73	7.26	13.27	9.37	31.85	23.08	13.94	9.65	38.36

Daily precipitation at selected stations in the San Joaquin watershed from Jan. 9 to Jan. 27, 1909.

[See flood charts for this period.]

Date.	Sanger.	Firebaugh.	North Fork.	Merced Falls.	Friant.	Yosemite.	Jacksonville.	Melones.	Lathrop.	Electra.	Jenny Lind.
Elevation.....feet..	371	154	3,000	321	355	3,945	602	750	19	670	.....
Jan. 9.....	0.00	0.14	0.78	0.24	0.42	1.78	1.92	1.96	0.52	1.54	0.00
Jan. 10.....	.00	.00	.20	.00	.10	.00	.12	.00	.00	.00	.00
Jan. 11.....	.24	.00	.00	.26	.00	.00	.00	.00	.00	.00	.30
Jan. 12.....	1.68	.34	.95	1.65	.38	.77	.16	.16	.32	.18	1.08
Jan. 13.....	2.16	.43	4.43	.74	1.86	3.47	2.90	2.12	.54	2.56	1.60
Jan. 14.....	.50	.06	4.42	.49	.88	3.17	1.76	4.56	.24	2.60	.68
Jan. 15.....	.00	.00	.61	.17	.12	.49	.36	.56	.04	1.08	.24
Jan. 16.....	.00	.00	.05	.00	.00	.67	.32	.58	.29	.42	.16
Jan. 17.....	.00	.00	.10	.00	.00	.07	.04	.12	.00	.22	.00
Jan. 18.....	.00	.00	.00	.00	.00	.00	.00	.08	.00	.58	.00
Jan. 19.....	.00	.00	.00	.22	.00	.00	.00	.00	.00	.00	.55
Jan. 20.....	.00	.16	.58	.79	.34	.79	.04	.70	.33	.78	.54
Jan. 21.....	.94	.49	4.04	.35	.96	4.18	1.56	2.10	2.30	1.64	2.00
Jan. 22.....	.00	.00	1.50	.40	.26	1.68	.60	1.04	.18	.82	.50
Jan. 23.....	.00	.17	.30	.00	.26	.78	.70	.70	.12	.50	.15
Jan. 24.....	.00	.00	.03	.68	.00	.00	.00	.01	.00	.06	.70
Jan. 25.....	.00	.05	.47	.74	.18	.75	.96	.86	.08	.64	.70
Jan. 26.....	.00	.75	.09	.70	.22	.60	.76	1.08	.20	.30	.30
Jan. 27.....	.00	.79	.52	.00	.46	.64	.70	.62	.03	.42	.00
Sum.....	5.52	3.38	19.1	7.43	6.44	19.8	12.9	17.2	5.19	14.3	9.50

*Hydrographs, Sacramento River system, March, 1907, and January, 1909.*

*Kennett, Cal.*

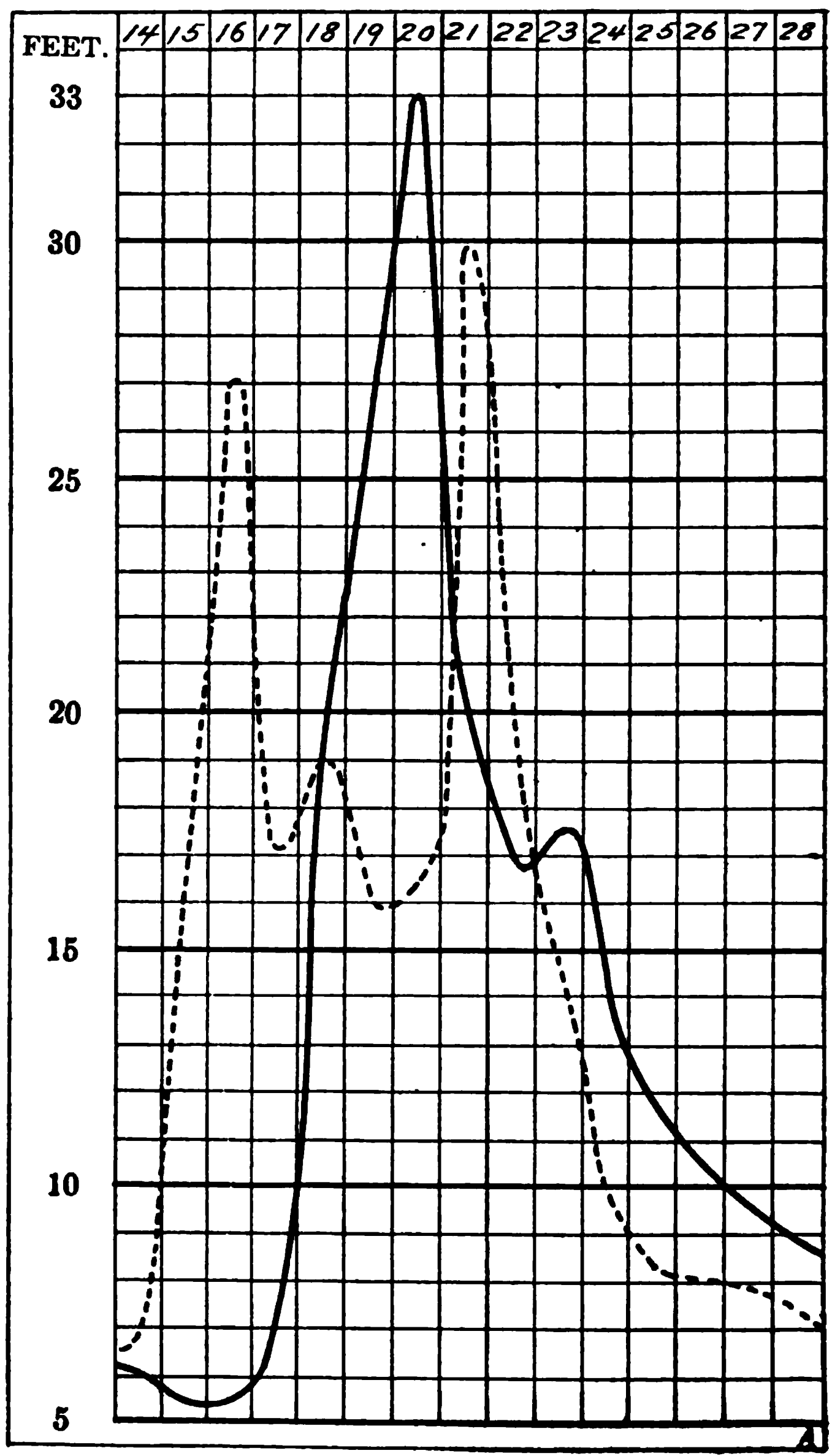


FIG. 28.—Solid line, March, 1907; dotted line, January, 1909.

*Hydrographs, Sacramento River system, January, 1909.*

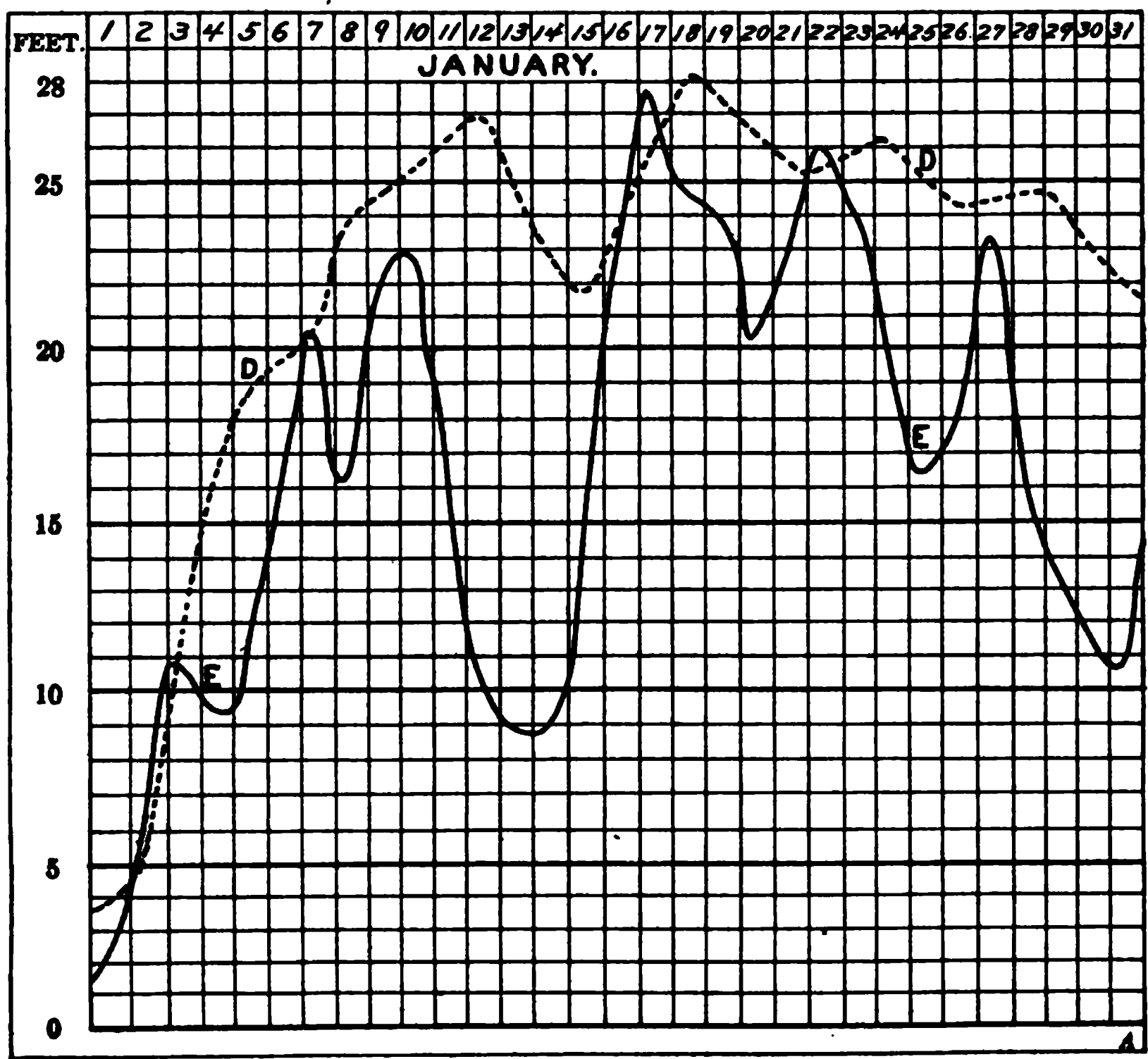


FIG. 29.—Hydrographs, January, 1909. D, Colusa; E, Red Bluff.

*Hydrographs, Sacramento River system, January, 1909—Continued.*

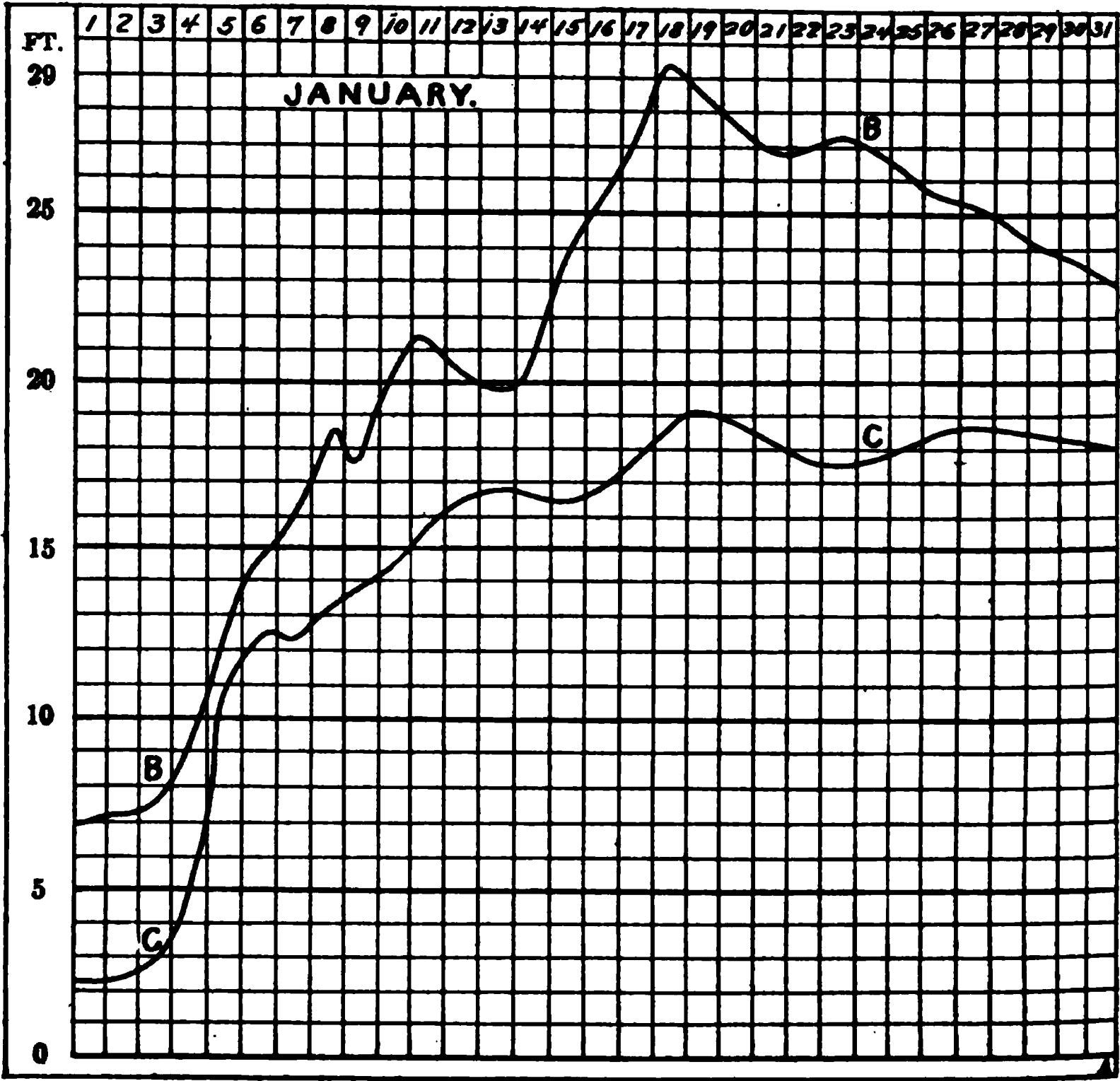


FIG. 30.—Hydrographs, Sacramento River, January, 1909. B, Sacramento; C, Knights Landing.

*Hydrographs, Sacramento River system, January, 1909—Continued.*

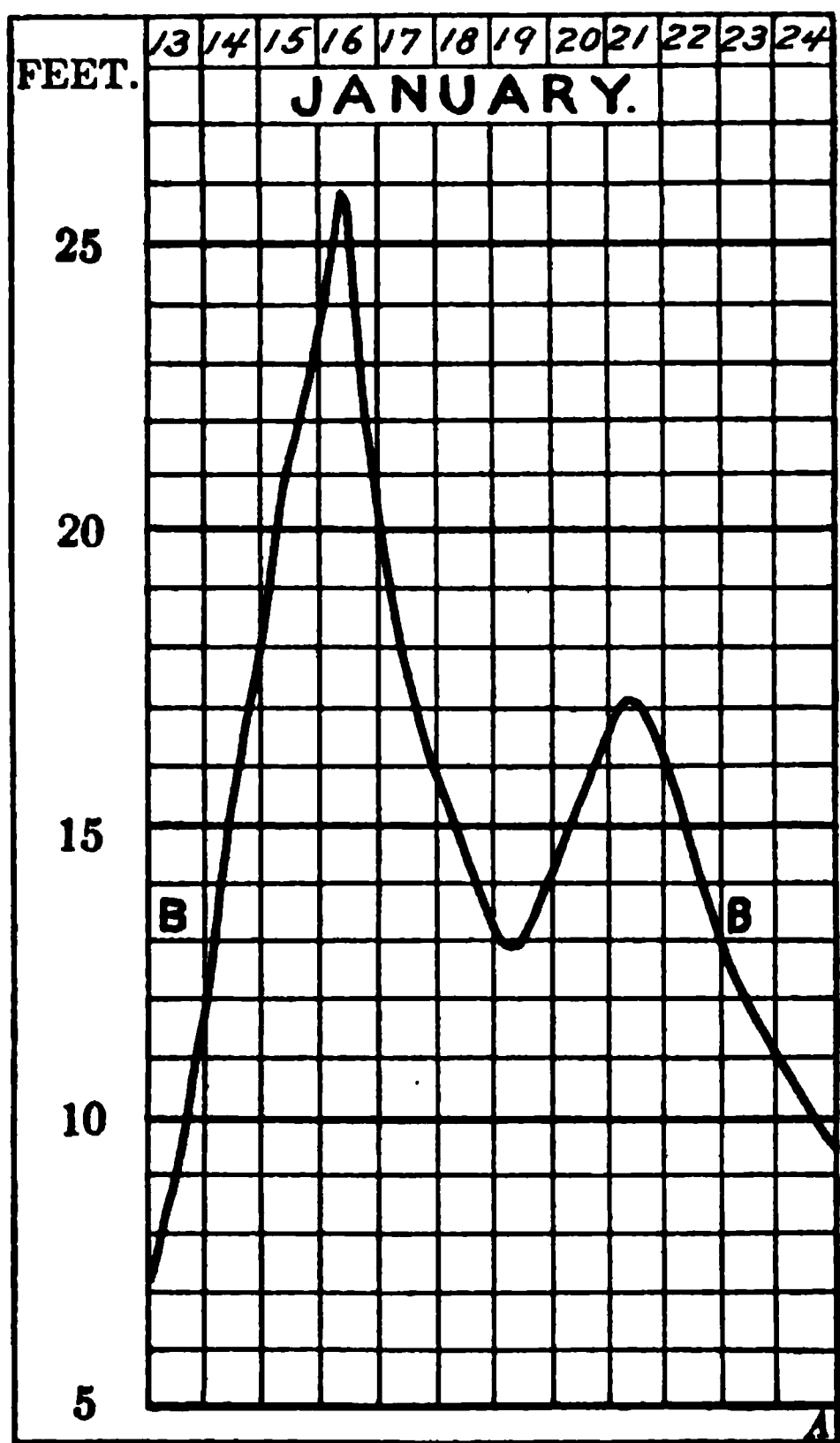


FIG. 31.—Hydrograph, Oroville on Feather.

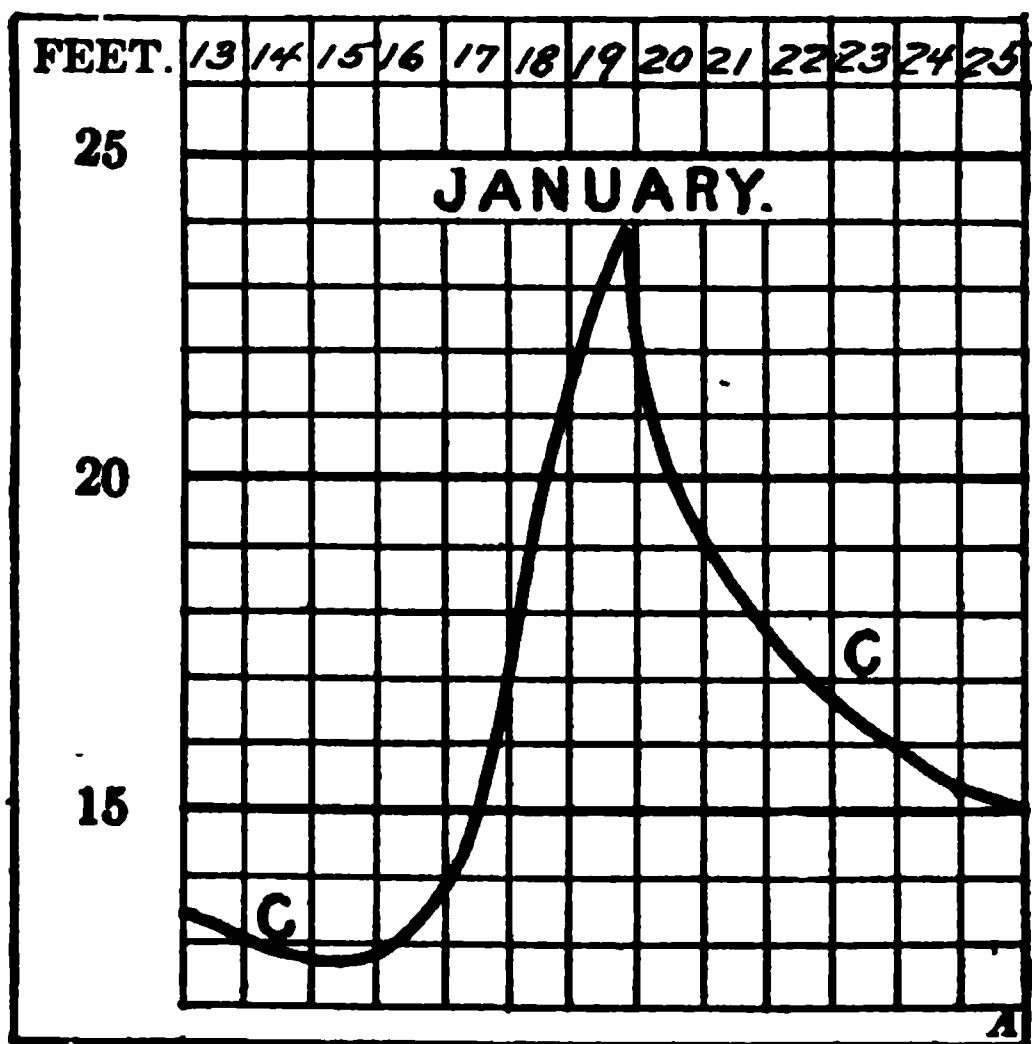


FIG. 32.—Hydrograph, January, 1909, Marysville on Yuba.

*Hydrographs, Sacramento and San Joaquin River systems.*

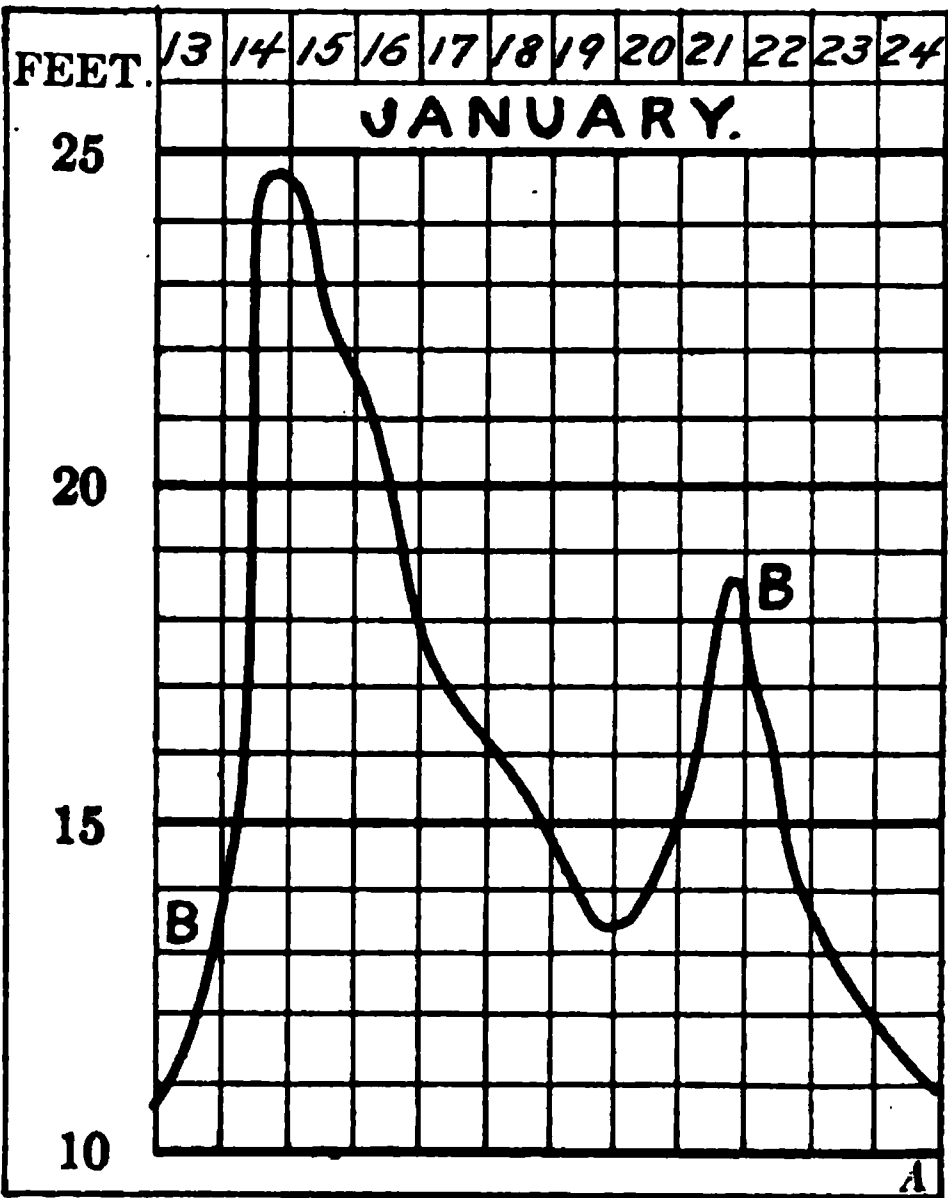


FIG. 33.—Hydrograph, Folsom on American, 1909.

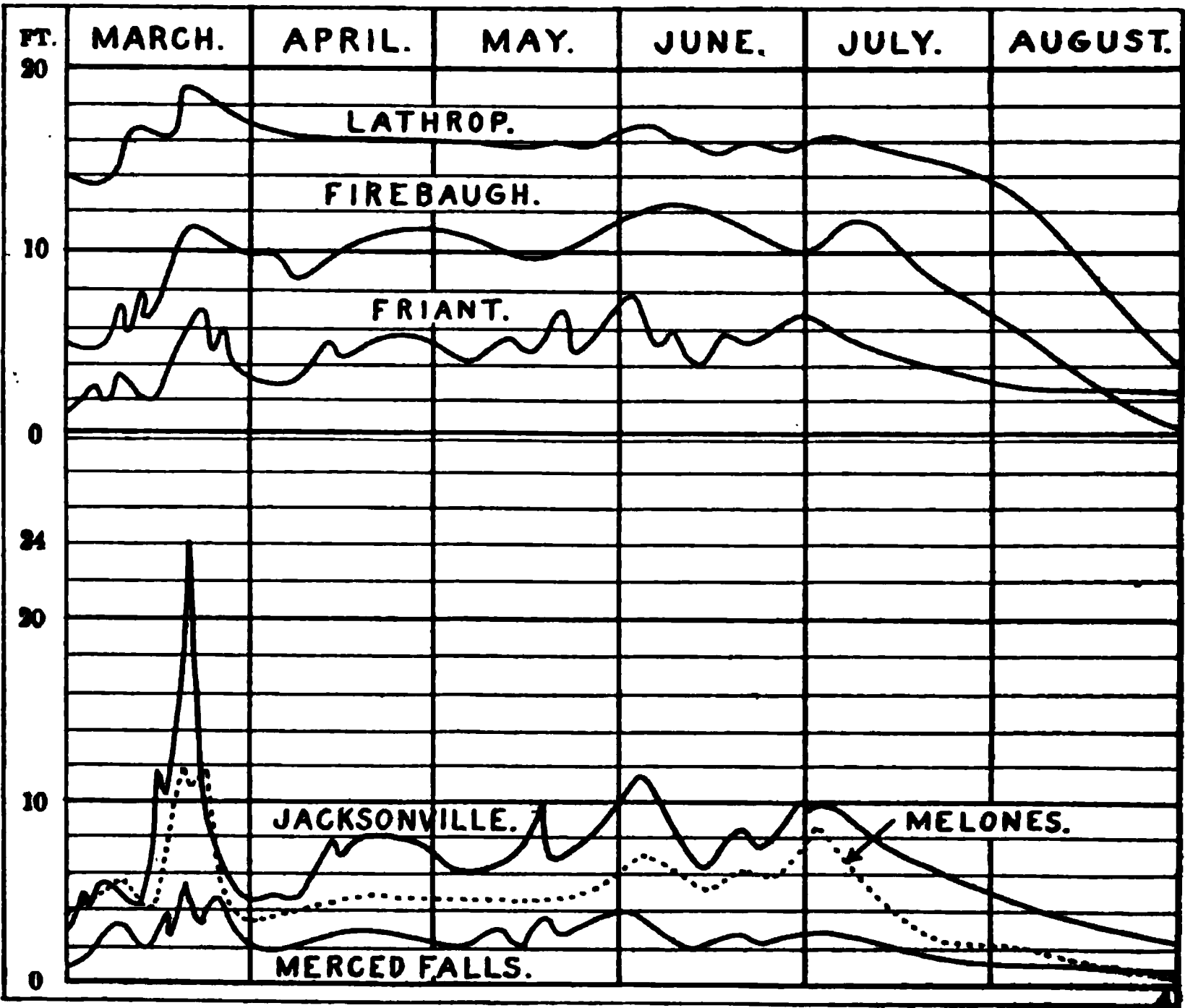


FIG. 34.—Hydrographs, San Joaquin River system, spring freshet, 1907.

*Hydrographs, San Joaquin system, March, 1907.*

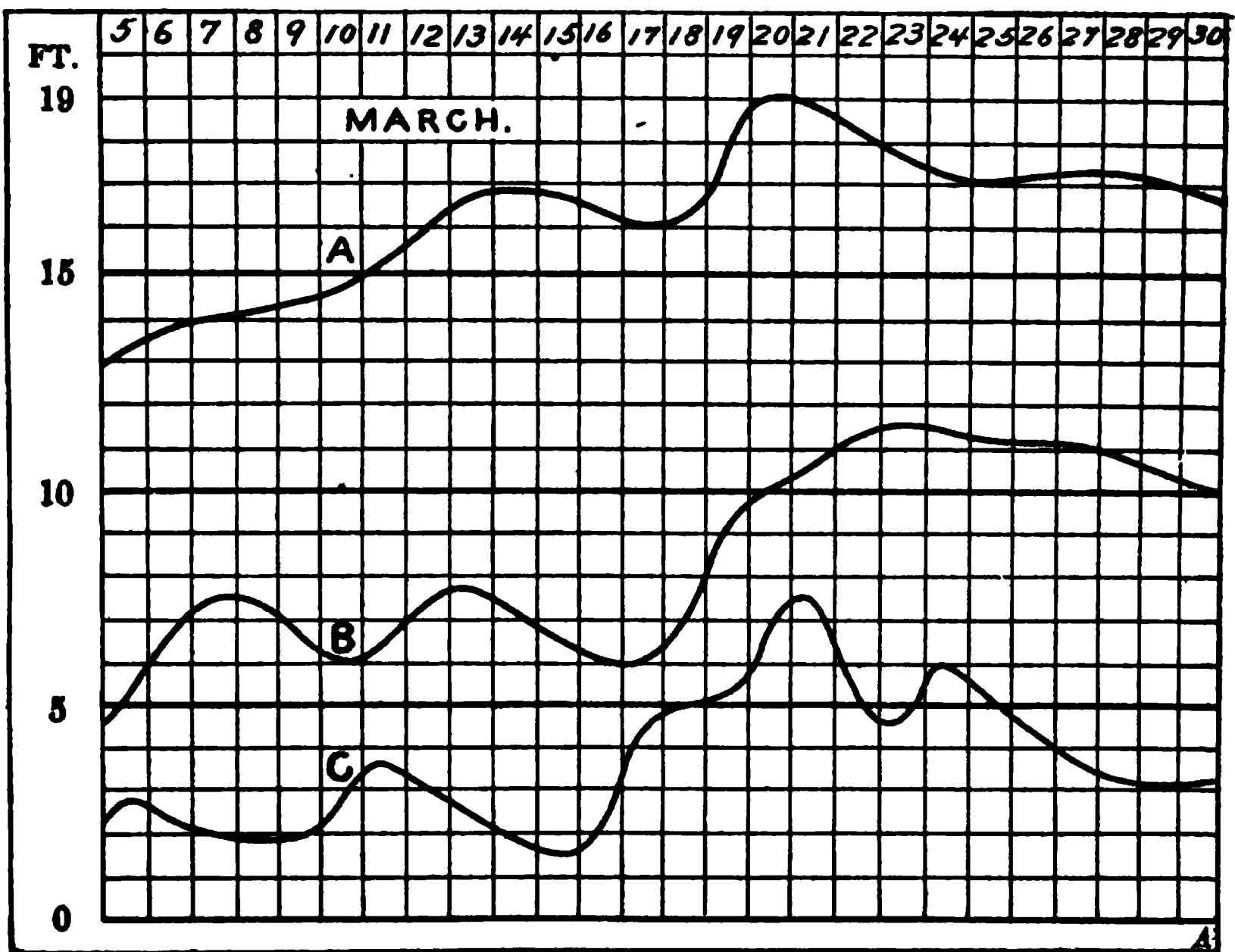


FIG. 35.—Hydrographs, San Joaquin, March, 1907. A, Lathrop; B, Firebaugh; C, Friant.

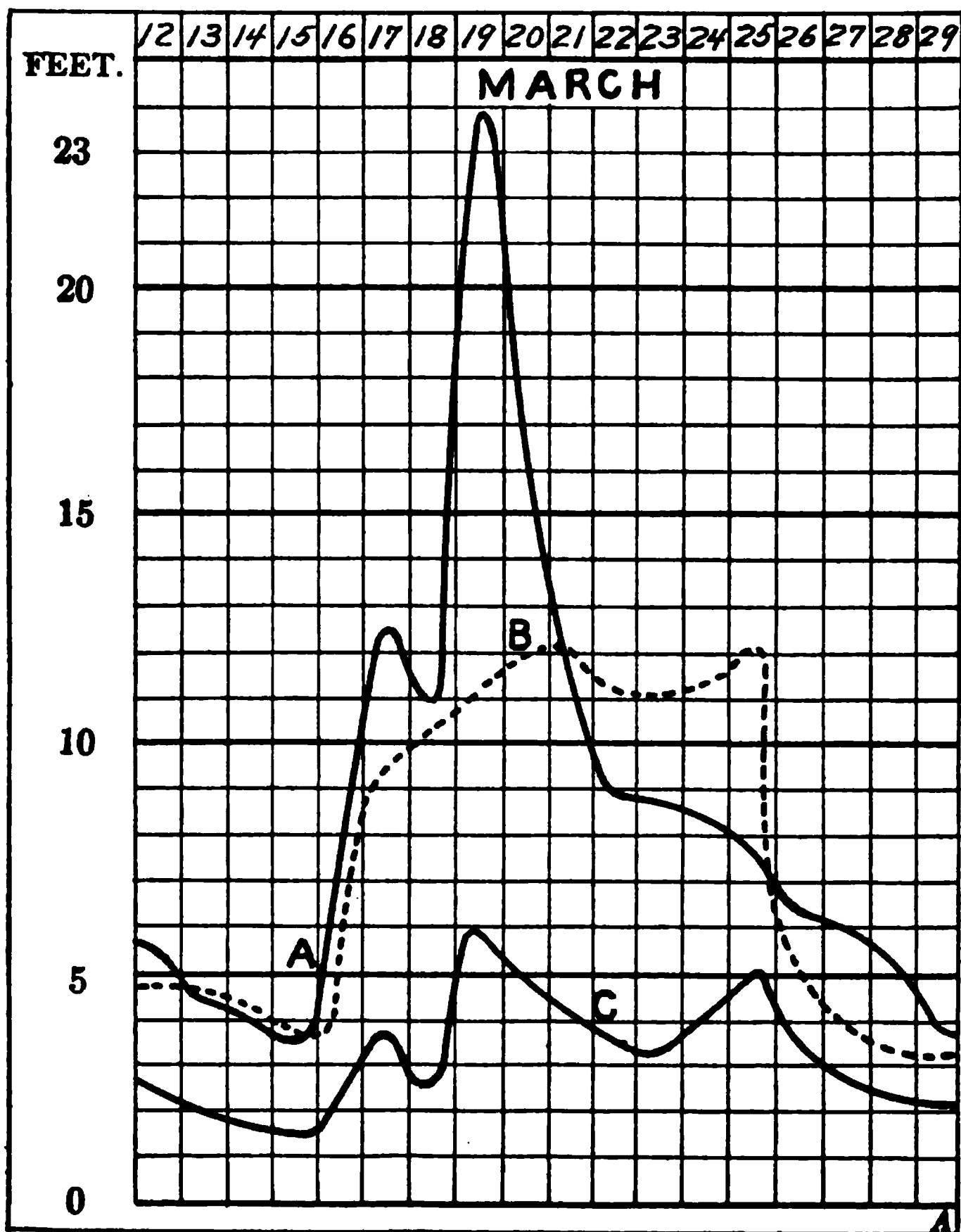


FIG. 36.—Hydrographs, March, 1907. A, Jacksonville; B, Melones; C, Merced Falls.



*Hydrographs, San Joaquin system.*

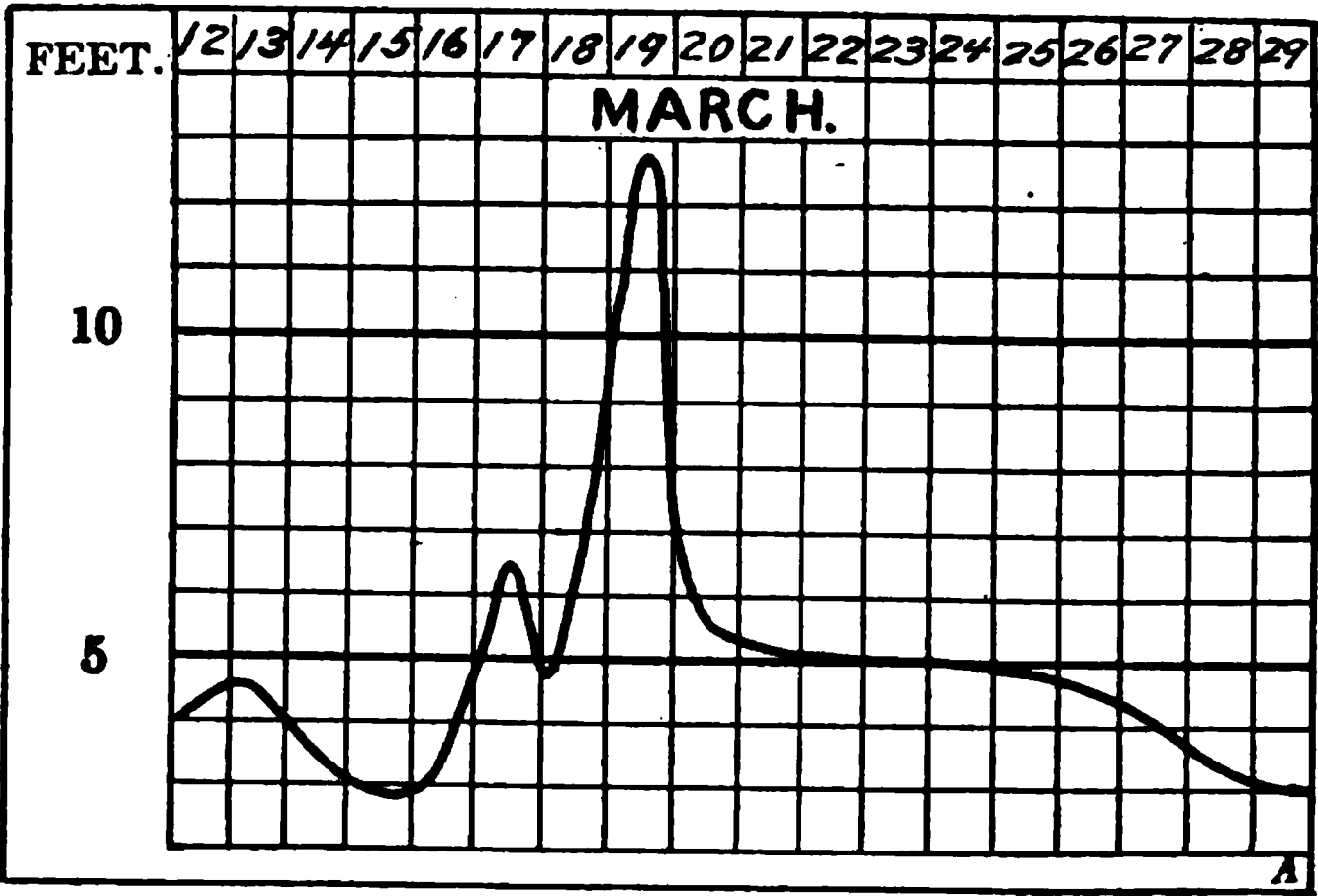


FIG. 37.—Hydrograph, March, 1907. Jenny Lind.

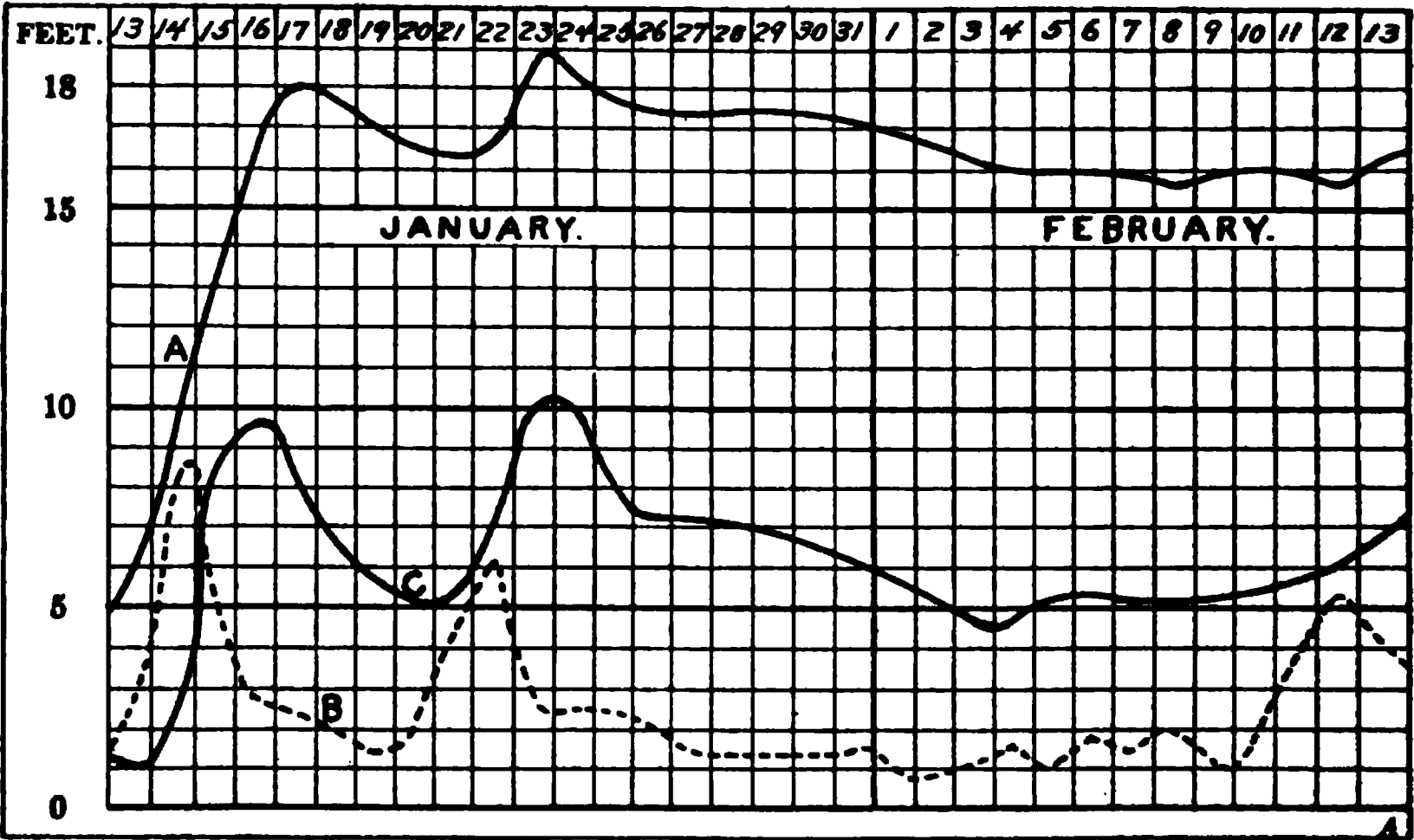


FIG. 38.—Hydrographs, San Joaquin, flood of 1909. A, Lathrop; B, Friant; C, Firebaugh.

*Hydrographs, San Joaquin flood, January, 1909.*

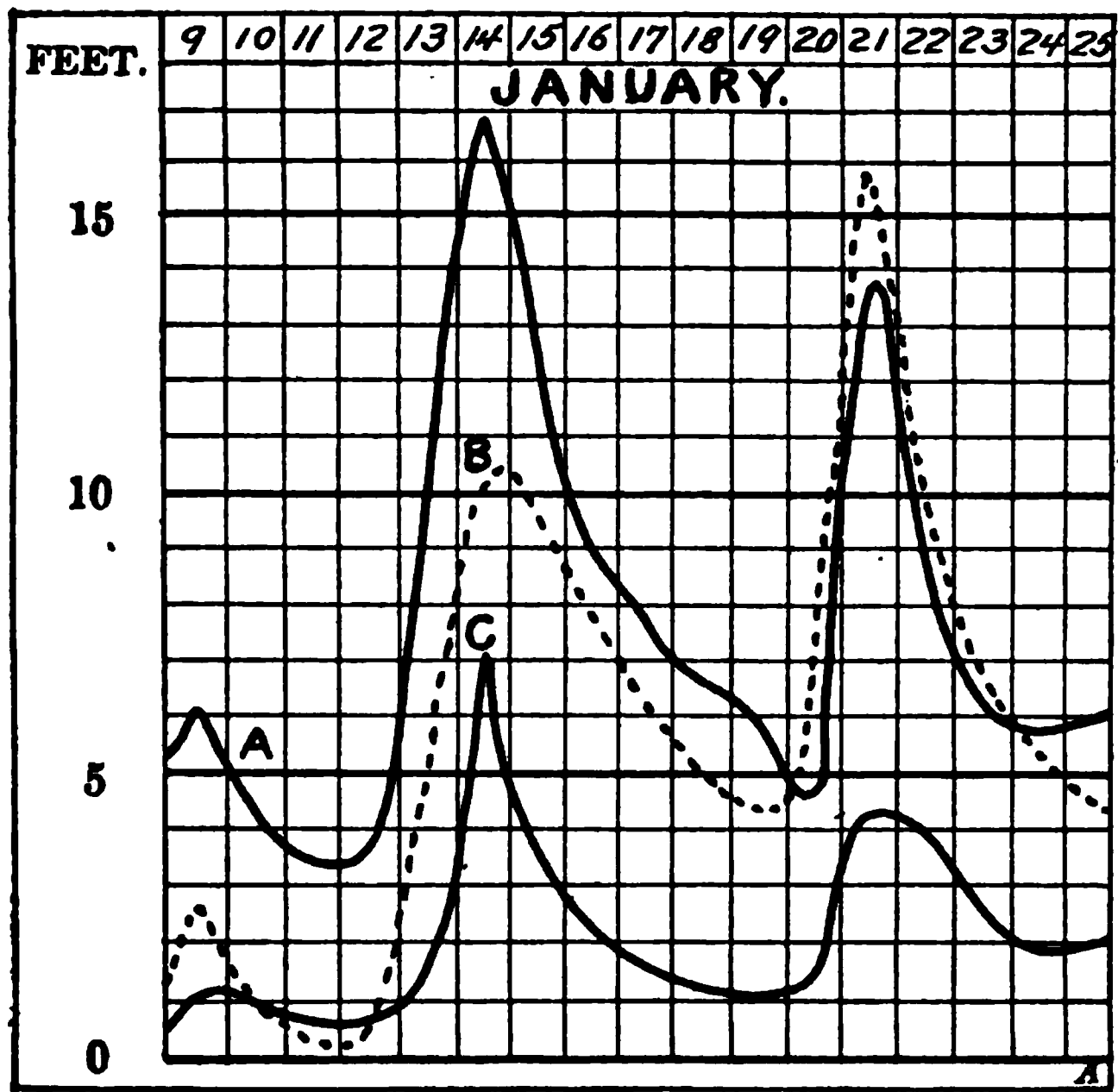


FIG. 39.—A, Jacksonville; B, Melones; C, Merced Falls.

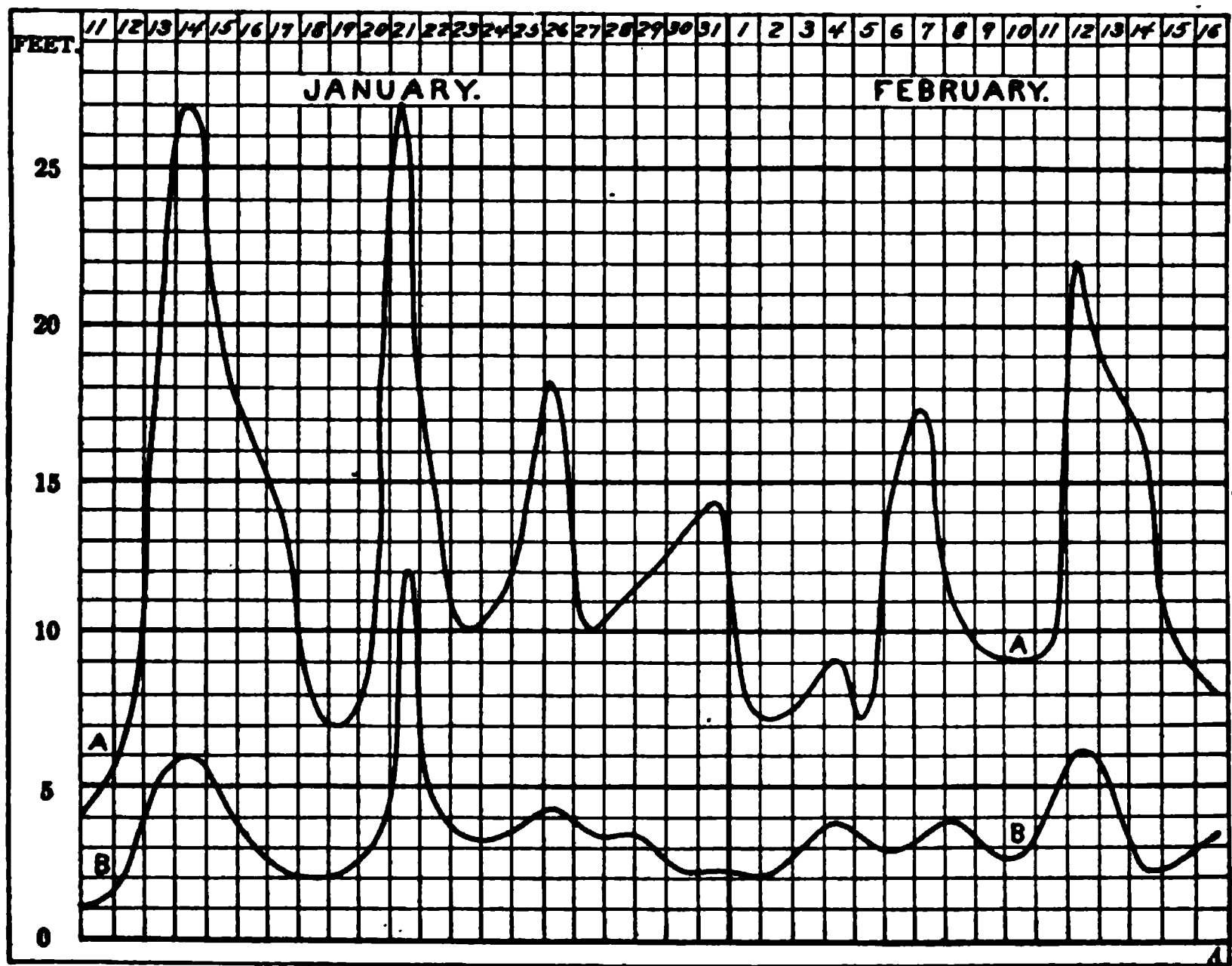


FIG. 40.—Hydrographs San Joaquin flood, January and February, 1909. A, Bellota; B, Jenny Lind.

This table, in addition to its value in connection with flood reports of this period, is of interest in showing the daily precipitation in the Sacramento watershed during an exceptionally wet month.

At Bellota, where the Calaveras is led into Mormon Slough, the river rose from 5 to 20 feet from the 12th to the 13th, and on the 12th reached a stage of 27 feet, the highest ever recorded at that point, resulting in serious floods over a large territory contiguous to Stockton, besides flooding portions of the city itself. All rivers in the San Joaquin watershed rose beyond their flood stages between the 14th and 15th and the San Joaquin itself, below the mouth of the Tuolumne, remained above the danger point until near the end of the month.

On the 14th of January the situation in the Sacramento Valley in connection with the great floods that occurred later first became serious. In order that conditions in the valley at this time be understood, it may be stated that the first abnormal swell of the season occurred between Colusa and Sacramento City between the 8th and 11th of January. The southern edge of this swell had barely passed the last-named point before the American River, under the influence of heavy rains and melting snows in the large area drained by its numerous feeders, rose 13 feet in a night, and on the morning of the 14th was carrying stages ranging from 15 feet a few miles above its mouth to 24 feet near its first fork, a few miles above Folsom. During the early morning of the 15th the full force of the American flood wave reached the Sacramento River with a volume sufficient to dislodge some of the bridges that spanned the American near Sacramento. The gauge at Sacramento registered 24.9 feet at 7 a. m. of the 15th, but a higher reading must have occurred sometime between midnight and 4 a. m., or during the period of the passing of the American wave. The Sacramento continued to rise at Sacramento City until 12.30 a. m. of the 17th, when it reached a stage of 29.6 feet. This is the highest stage of which there is an authentic record. In the meanwhile the heavy rains throughout the drainage basins of both watersheds had swollen all watercourses beyond their carrying capacities, and many points on the main rivers were being flooded.

On January 16, it was estimated that the Sacramento River was carrying a flood wave from 1 to 2 feet above what may be termed the "danger point" from Red Bluff to Courtland, a distance of over 200 miles.

By the morning of the 17th the Sacramento River between Sacramento and Walnut Grove felt the relief afforded by the escaping waters through breaks in the west side levees, but the flooded area above, especially in the vicinity of Monroeville and St. John, was increasing. By 8 a. m. of this date the town of Broderick, just across the river from Sacramento, had mostly become inundated from the back water of Yolo Basin.

Courtesy Great West

FIG. 45.—WRECK OF WESTERN PACIFIC BRIDGE OVER AMERICAN RIVER, JANUARY, 1909.



Courtesy Great West.

FIG. 48.—FLOOD SCENE, 1908, IN YOLO BASIN, OPPOSITE SACRAMENTO.



Courtesy Great West

**FIG. 47.—TRACKS OF SOUTHERN PACIFIC RAILWAY CO. IN YOLO BASIN OPPOSITE SACRAMENTO—FLOOD OF 1909.**



[illegible]

On the 18th the river at Sacramento had subsided to 28 feet, but by night of this date the flood waters of the Sacramento and those of the San Joaquin were rapidly approaching the delta. By the 19th the great volume of water that had accumulated in Yolo Basin began finding its way back into the Sacramento through Steamboat Slough and thence into the Lower San Joaquin through the various sloughs that connect the two rivers in the vicinity of the Lower Islands, so called.

From the 19th to the 27th inclusive flood conditions prevailed throughout all districts contiguous to the junction of the Sacramento and San Joaquin Rivers, and during this period many agricultural tracts and islands were either partly or wholly flooded. (See list of lands flooded in the "Island districts," p. 91.)

The January flood had barely subsided before heavy rains in the upper Sacramento Valley resulted in damaging floods in the valley north of Colusa. On February 3, all low lands lying between Tehama and Hamilton were under water, and the river between Redding and Monroeville, a distance of 99 miles, was carrying more water than during the floods of March, 1907, or those of January, 1909. In the vicinity of St. John, Monroeville, and Hamilton and thence eastward nearly to the town of Chico, it was estimated that fully 100,000 acres of land were submerged. Tehama was almost completely flooded, there being nearly 10 feet of water in some of the lower sections of the town.

There was little effect of the upper Sacramento flood felt below Colusa on account of the fact that the river flowed freely into the various basins through the breaks caused by the floods of the preceding month. Yolo Basin, however, was fuller than at any time during the previous floods, and it has been stated that the discharge of this sink into the Sacramento River above Rio Vista was sufficient to reverse the current of the Sacramento for a considerable distance above the mouth of Steamboat Slough.

From many reports that have been received from all sections covered by the floods those of 1909 were the most general and widespread of any previous inundations. They were as disastrous as any previous flood of which there is an authentic history, and probably more so, for the reason that, in addition to the large number of old levees broken, there were many new districts in process of reclamation which were inadequately protected by levees not yet completed. It has been estimated that over 300,000 acres of land were, at various times flooded during the January and February floods of 1909. The map reproduced in this bulletin as figure 48, p. 90, through the courtesy of the Great West, from data furnished by the bureau, shows approximately the area that was flooded in the Sacramento Valley during the floods of 1907 and 1909.

THE FLOODS OF JANUARY AND FEBRUARY, 1911.

On January 30, 1911, heavy, warm rains began falling in the headwaters of the tributaries of the San Joaquin, which resulted in the greatest flood in the history of the Lower San Joaquin Valley.

Daily precipitation at selected stations in the San Joaquin watersheds Jan. 20 to Jan. 31, 1911.

[See hydrographs, figs. 41 to 43, for this period.]

Date.	Fire- baugh.	North Fork.	Merced Falls.	Friant.	Yosem- ite.	Jack- son- ville.	Me- lones.	La- throp.	Elec- tra.	Jenny Lind.
Elevation.....feet..	154	3,000	321	355	3,945	602	750	19	670	.....
Jan. 20.....	0.36	0.85	0.17	0.06	0.40	0.44	1.10	0.36	1.26	0.94
Jan. 21.....	.00	.23	.91	.34	.04	1.30	1.34	.72	1.34	.00
Jan. 22.....	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Jan. 23.....	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Jan. 24.....	.40	3.20	.74	.64	.90	1.04	1.28	.74	1.46	1.16
Jan. 25.....	.34	2.60	.77	1.28	.79	2.20	2.00	.82	1.60	.82
Jan. 26.....	.00	.00	.04	.12	.00	.32	.26	.12	.82	.46
Jan. 27.....	.00	.00	.04	.00	.00	.10	.22	.12	.62	.04
Jan. 28.....	.00	.35	.05	.02	.27	.20	.46	.00	.22	.20
Jan. 29.....	.18	2.12	.17	.20	.48	.46	.36	.32	.44	.40
Jan. 30.....	1.20	2.86	2.73	1.84	1.20	3.50	4.40	.92	3.42	2.40
Jan. 31.....	.60	1.57	2.30	1.08	.06	3.06	3.02	.55	2.80	1.62
Sum.....	3.08	13.8	7.92	5.57	4.14	12.6	14.4	4.67	14.0	8.04

About 24 hours after the beginning of the rains the flood waters of the Merced, Stanislaus, and Tuolumne Rivers had practically reached the main stream, and three flood waves of great intensity began moving down the San Joaquin. The combined force of these waves reached the lowlands in the vicinity of Lathrop and San Joaquin Bridge during the day of February 1, and by night of this date many thousands of acres of land became flooded. Many head of stock were drowned between Mendota and Lathrop, and in the vicinity of San Joaquin Bridge there were many residences either washed away or else undermined. It has been estimated that ten thousand or more acres were under water between Firebaugh and Lathrop. By the morning of February 2 the flood waters had spread over a large territory between Lathrop and Roberts Island, destroying a number of levees and inundating several thousand acres of reclaimed land. In the meanwhile the Mokelumne had poured its flood waters into the lowlands, doing considerable damage. During this flood the Calaveras overflowed its banks after reaching Mormon Slough and flooded several thousand acres of land between Bellota and Stockton. The city itself was probably saved from one of the most disastrous floods in its history by a diverting canal, which deflected the water of Mormon Slough and carried it down into the Calaveras proper below Stockton. It has been conservatively estimated that fully 75,000 acres of land were overflowed in the San Joaquin Valley between Stockton and Mendota and in the vicinity of Bellota and Linden during the floods of January and February, 1911.

*Hydrographs, San Joaquin flood, January-February, 1911.*

FIG. 41.—Hydrographs San Joaquin flood, 1911. A, Lathrop; B, Firebaugh; C, Friant.

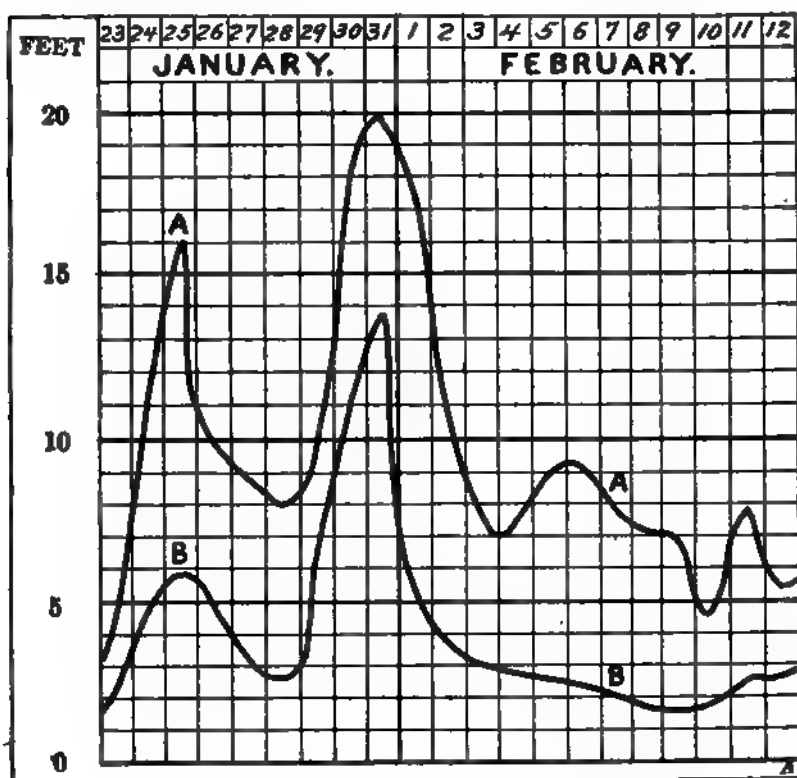


FIG. 42.—Hydrographs, January and February, 1911. A, Bellota; B, Jenny Lind.

*Hydrographs, San Joaquin flood, January-February, 1911—Continued.*

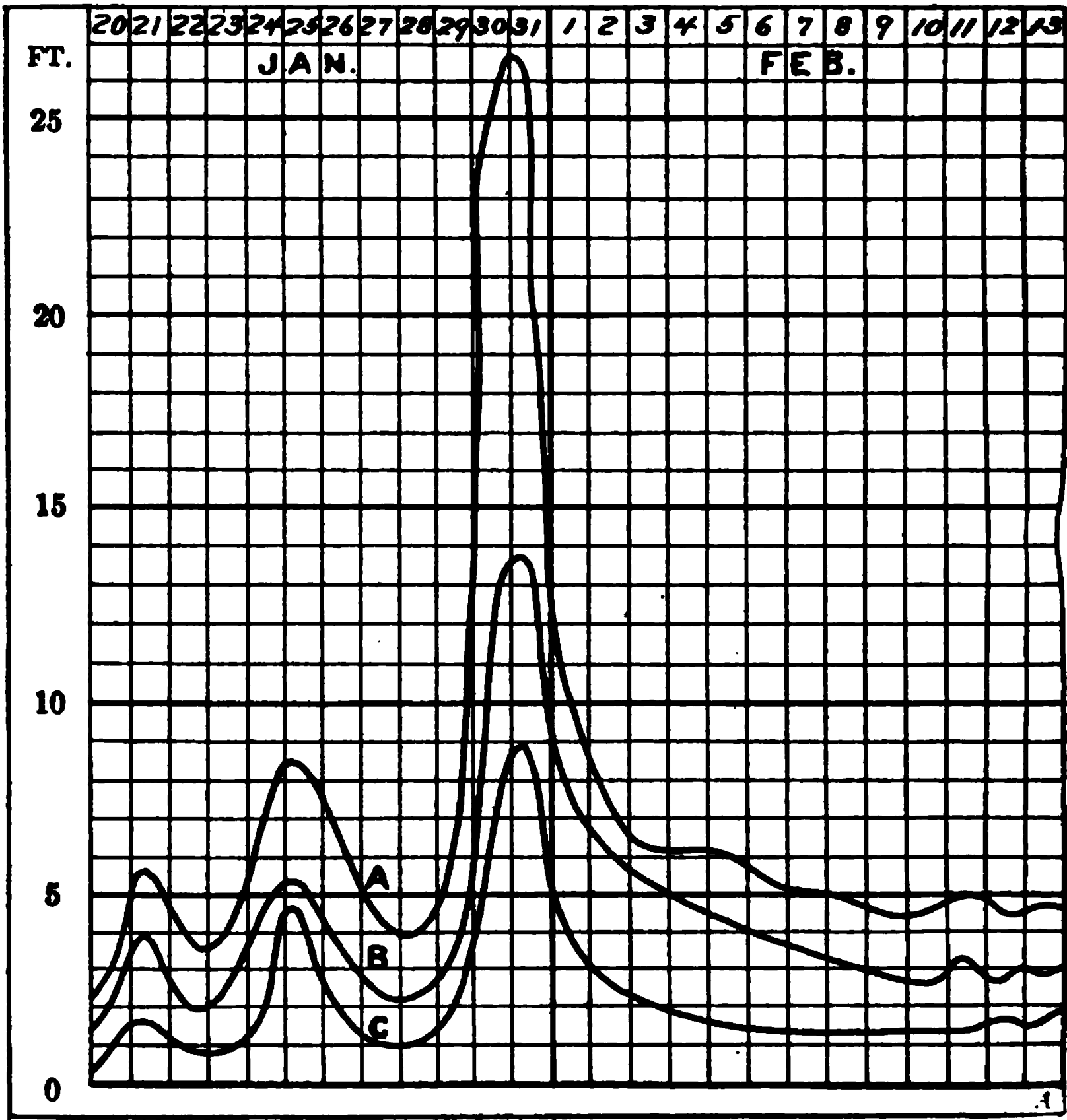


FIG. 43.—A, Jacksonville; B, Melones; C, Merced Falls.

River conditions in the Sacramento Valley again became critical in March, 1911, and a stage of 27.4 feet was recorded at Colusa on the 9th of that month. Heavy rains in the foothills that form the western boundary of Colusa Basin resulted in what is known as the "Trough" of this basin, reaching the highest stage ever before known. The water in this trough continued to menace the back levees that protected it from the foothill drainage, and finally, on April 25, 1911, those which protected reclamation No. 108 gave way, flooding 25,000 acres of land, the most of which was planted to grain, the entire crop being destroyed.

From April, 1911, to January 28, 1912, the date of this report, there have been no floods in the central valleys of California.

#### WARNINGS.

During all the floods that occurred in 1907, 1909, and 1911 the Weather Bureau issued warnings to every point involved from 12 hours to as much as 3 days in advance of the approach of the flood waters. Advices from the bureau regarding the great floods that prevailed in the delta lands of the Sacramento and San Joaquin Rivers in 1907 and 1909 not only indicated the intensity of the floods, but timed their approach within a couple of hours three days in advance.

The table below shows approximately the losses that were sustained in the Sacramento and San Joaquin Valleys during the floods of 1904, 1907, 1909, and 1911, and the amount that was saved by reason of the warnings that were issued by the Weather Bureau during those of 1907, 1909, and 1911.

#### LOSSES IN THE CENTRAL VALLEYS OF CALIFORNIA DURING THE FLOODS OF 1904, 1907, AND 1909.

From reliable reports, and from data which have been gathered from time to time during the past four years, it is estimated that losses due to floods in the drainage basins of the Sacramento and San Joaquin Valleys during the floods noted above aggregate over \$10,000,000.

The losses have been divided as follows:

Buildings.....	\$200,000
Lumber.....	75,000
Levees.....	3,500,000
Stock.....	200,000
County roads.....	1,000,000
County bridges.....	900,000
Railroads, including roadbeds and bridges.....	2,000,000
Crops destroyed.....	1,250,000
Damage to lands by erosion.....	500,000
Losses sustained by suspension of business.....	200,000
From all other causes.....	500,000
Total.....	10,325,000

The amount saved during the floods of 1907 and 1909 by reason of the timely warnings that were issued by the Weather Bureau aggregate close to \$2,000,000. This amount is quoted from estimates that have been received from all sections covered by the floods. It has been admitted that the amount saved would have been much greater had the warnings been heeded in all cases.

#### THE FLOOD PLANE OF THE SACRAMENTO RIVER.

In studying the tables of high stages in the Sacramento River at Sacramento City and at other points in the Sacramento Valley, it will be noted that the flood plane has become higher each year; that since the high water of 1850 almost each succeeding flood has been higher than that of its predecessor. In fact, the expression so often heard among river men to the effect that the rivers are rising higher each year has, up to the flood of 1909, become a recognized fact.

The ever-increasing flood plane in the Sacramento River at all points above the mouth of the Feather is, no doubt, due (1) to the increased height and strength of the levees along the river banks, and (2) the constant enlargement of reclamation areas. Both of these causes have, at most points, restricted the natural bed of the river to a channel at no time wide enough to carry its discharge under extreme conditions. The same may be said of the Lower Sacramento, American, Feather, Bear, and Yuba Rivers, except that the predominating cause in the raising of the high-water plane in these streams is the amount of mining débris that has been deposited in their beds. Until March 1, 1893, when a law was passed restricting hydraulic mining, millions of cubic yards of débris were annually being dumped into the upper reaches of these rivers; and, as it slowly found its way downstream, the finer particles advancing at moderate stages and the coarser and heavier matter moving farther and farther down with each succeeding high water or freshet, it not only became a serious menace to the agricultural lands on both sides of the rivers by causing overflows at moderate stages, but affected the navigability of the lower Sacramento River and for a time practically eliminated the Feather River from its mouth to its junction with the Yuba as a navigable stream.

According to notes kindly furnished by Mr. W. T. Ellis, jr., member of the State reclamation board, and for many years president of the Marysville Levee Commission, both the Feather and Yuba Rivers were navigable for a considerable distance above Marysville in the early days of the State's history. This is evidenced by the fact that in 1849 the steamer *Linda* came around the Horn from an Atlantic port and made a trip up the Yuba for a distance of 4 miles above Marysville. In notes, also furnished by Mr. Ellis, it is stated that the steamer *Phoenix* made a trip up the Yuba as far as Owsleys Bar

in 1854. In fact, it is a matter of authentic record that before the Feather and Yuba were filled with mining débris Marysville was the natural distributing point for the northern mining section of the State. It is of record at Marysville that on August 27, 1850, there were 24 sailing vessels in the "port" of Marysville, and on August 22, 1851, there arrived at Marysville 7 steamers with full cargoes. In the news columns of the Sacramento Bee of February 16, 1862, it is noted that the steamer *Defiance* made several trips to Oroville with freight during the months of January and February, 1862.

As an illustration of the depth of the bed of the river at Marysville before the filling in by mining débris, Mr. Ellis states that it is a matter of record that during the great flood of 1861-62, when almost the entire Sacramento Valley was inundated, including the city of Sacramento, the flood waters did not reach what was then and is still the main business portion of Marysville. While there are no records of the discharge of the flood waters at that time, they were, no doubt, much greater than those of 1907. It is of record that the rainfall at Nevada City during the winter of 1861-62 was 115 inches, and assuming that the same amount occurred at corresponding elevations in the Feather-Yuba watershed, makes it almost certain that the discharge of 1861-62 was far in excess of the 1907 and 1909 floods, when Marysville experienced considerable difficulty in protecting itself from overflow.

According to reports of engineers during the first 20 years of unrestricted hydraulic mining, from 1849 to 1869, the low-water plane of the Sacramento River at Sacramento City was raised 2.9 feet; that during the next 10 years, 1869 to 1879, the rise of this plane was doubled. Some engineers claim that the low-water plane from 1849 to 1900 was raised fully 7 feet. Col. Mendell, in his report, states that as a consequence of the elevation of the bed of the Sacramento River the tidal influence which in 1849 extended up as high as the mouth of the Feather, 25 miles above Sacramento, and was quite 2 feet at Sacramento, is now no longer noticeable above Hancock Shoals, 9 miles below Sacramento.

Capt. Thomas H. Jackson, United States Corps of Engineers, in connection with his examination and survey of the Sacramento River from its mouth to the Feather in 1908, states as follows:

A comparison of this survey with that of 1895-96 shows that the river is improving as a navigable channel; that it is recovering from the effects of hydraulic mining. It is estimated that the river bed for a distance of 14 miles below Sacramento has lowered 2 feet within the past 12 years. The American and Feather Rivers, however, are still full of débris, and the effect of the sand deposits in the American River on the Sacramento River are noticeable for a considerable distance below the mouth of that river, and the fact that these two rivers contain probably more than 500,000,000 cubic yards of material, all of which must eventually pass down the Sacramento River to Suisun Bay, must be borne in mind in any consideration of the improvement of the river.



It is quite evident, however, that there has been a further improvement in the bed of the Sacramento River in the vicinity of Sacramento City and, no doubt, for some distance below, since the floods of 1909, as during the low-water period of 1910 it was noted that the tides extended quite to the mouth of the American River, and at times swelled the Sacramento River in the vicinity of Sacramento City as much as 0.4 foot. During August and September, 1912, when the river at Sacramento probably reached the lowest point in the history of the city, tides exceeding 1 foot were noted.

#### FLOOD BASINS OF THE SACRAMENTO RIVER.

Numerous basins on both sides of the Sacramento River have at all times exercised a modifying influence on the floods in this stream by freely admitting the overflow, either through weirs constructed for this purpose or through breaks in the levees. On the east side of the river are four distinct depressions known as Butte, Sutter, American, and Sacramento Basins. In a report of the commissioner of public works to the governor of California in 1894, which report is quoted in a paper before the American Society of Engineers, by W. B. Clapp and others, the following areas and capacities of these basins are given: Butte Basin is north of Marysville Butte and has an area of from 30 to 150 square miles, depending upon the river stage, and a capacity of 460,000 acre-feet at flood stages. It discharges through Butte Slough into Sutter Basin. Sutter Basin is south of Marysville Butte and north of the Feather River. It has an area of 138 square miles and a capacity of 890,000 acre-feet at flood stages. It discharges through sloughs into the Sacramento River above the mouth of the Feather. The American flood basin is south of the Feather and north of the American. It has an area of 110 square miles and a capacity of 571,000 acre-feet at flood stage. It discharges into the Sacramento River north of the city of Sacramento. This basin is of considerable depth at its lowest point, and even during the extreme low water of 1912 contained a large amount of water. At the present time practically all of the American Basin is being leveed with a view to its complete reclamation, and it is expected that it will eventually be eliminated as a flood basin. The Sacramento Basin, so-called, is a narrow depression south of the American and extends thence southward nearly to Walnut Grove. Its area and capacity have not been determined. In fact this basin, if such it may be called, has long ago been reclaimed although its lower or southern end is liable to overflow from the Mokelumne River, when this stream is out of bank, and from the Sacramento in the event that its east side levees give way. Yolo Basin, on the west side of the Sacramento River, was originally one unbroken depression extending from Stony Creek on the north to the

mouth of Cache Slough on the south, but it is now divided into two well-defined basins by a ridge that was formed by overbank flow and sediment deposit from the original channel of Cache Creek, which at one time discharged direct into the Sacramento River. This ridge terminates just north of Knights Landing and extends back toward the foothills. North of this ridge is now known as Colusa Basin and south of it is Yolo Basin. Quoting from the Report of Public Works in 1894, Yolo Basin is 50 miles long and 7 miles wide with a capacity of 1,115,000 acre-feet. It discharges into Cache Creek and thence into the Sacramento River through Steamboat Slough.

Colusa Basin is some 45 miles long and from 2 to 7 miles wide, with a capacity of 690,000 acre-feet at flood stage. Until within the past few years Colusa Basin discharged into the Sacramento through Sycamore Slough, but the various processes of reclamation have altogether altered flood conditions both with regard to the water that flows in from the western hills and that from the river. A back levee protects the basin from the hill water and a canal between this levee and the hills now carries the hill drainage into the Sacramento near a point where the lower Sycamore Slough once joined the river at Knights Landing. During the floods of 1907 and 1909 the water that escaped into Colusa Basin from the Sacramento side, where many levees broke, flowed over Knights Landing Ridge into the Yolo Basin. Colusa Basin has, however, been almost entirely if not quite reclaimed and has practically been eliminated as a flood basin. Plans have been made for the cutting of Knights Landing Ridge which, in connection with the west side canal, will make a branch river to which all hill streams will be tributary, leading them down into and eventually through Yolo Basin.

During the 1907 and 1909 floods the protecting levees on the west side of the Feather River, about opposite Marysville Butte, were destroyed by an enormous rush of water which flowed overbank at Hamilton Bend. This water came across the plains to the north of the buttes with such force and volume as to rush directly across the flooded Sacramento River, and after tearing out the west side levees it continued down through Colusa Basin, leaving destruction in its wake. During the 1907 flood the water in Colusa Basin was level with the crest of Knights Landing Ridge, but in 1909, according to measurements made by Mr. G. B. Herington, consulting engineer, Sacramento, Cal., it flowed 4 feet deep over the ridge into Yolo Basin. It was the backwater from this overflow that flooded Knights Landing during the 1909 flood and that kept that town under water for about 41 days. Massive levees have now replaced those that were demolished at Hamilton Bend, and it is not thought that Colusa Basin will again be menaced by the Feather River. (For map of overflowed region, see fig. 48, p. 90.)

FIG. 48.—Inundated region in Sacramento Valley.

## DELTA LANDS OF THE SACRAMENTO AND SAN JOAQUIN.

In the lower reaches of the Sacramento and San Joaquin Rivers are numerous low tracts of land and many islands, all of which have been built up by silt from both streams. Some of the islands are composed of a combination of silt and peat. The reclamation of these lands, which are the most productive on earth, has necessitated the erection of levees not only strong enough to withstand a long siege of high water, but also to resist the action of winds and tides, both of which are strong factors during periods of high water.

On account of the numerous islands that are separated from the mainland and the many tracts that are dissected by sloughs and other waterways, and the wide range of tides in the lower districts, no Weather Bureau gages have been established in the delta below Rio Vista. Mr. W. E. Meek, a prominent citizen of Antioch, with large agricultural interests in the island districts, made measurements in parts of the lower San Joaquin River during the floods of 1907, 1909, and 1911.

In comparing the floods in the delta of 1907 and 1909, Mr. Meek states that the highest water reached in 1907 was exceeded by that of 1909 in all of the lower districts. In the San Joaquin River above Stockton, however, the crest of the 1907 flood was about 0.5 of a foot higher. During the 1911 floods the water in the lower San Joaquin between Stockton and Mendota was between 2 and 3 feet higher than ever before recorded. But, as stated by Mr. Meek, it did not come within 18 inches as high in 1911 as it did in 1909 on the following-named islands: Andrus, Bradford, Jersey, Sherman, and Twitchel.

The following-named lands in the delta were flooded in 1907: Andrus Island,<sup>a</sup> Bethel tract,<sup>a</sup> Bouldin Island,<sup>a</sup> Brannan Island, Burke tract, Byron tract, Clifton Court tract, Coney Island, Elmwood tract, Franks tract, Jersey Island,<sup>a</sup> lower Jones tract, Lower Sherman Island,<sup>a</sup> Moss tract, Ridge tract, Ryer Island, Sargent Burnhardt tract, Statin Island, Stone tract, Terminus District, Twitchel Island,<sup>a</sup> Tyler Island, Venice Island,<sup>a</sup> Victoria Island, and Webber tract, aggregating 130,744 acres.

## CONCLUSION.

During the past few years large interests have recognized the ultimate value of all reclaimable lands in the central valleys of California. In the Sacramento Valley especially millions of dollars are now being applied to the work of reclaiming the various flood basins heretofore considered as waste land. According to the Report on the Control of Floods in the River Systems of the Sacramento and San Joaquin Valleys, published in 1911, there are 48 reclamation

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<sup>a</sup> Also flooded in 1909.

districts in the Sacramento Valley itself. Reports on 41 of these districts, with an area of 217,904 acres, showed on July 1, 1909, that 205,423 acres have been completely reclaimed and 99,376 acres partly reclaimed by the construction of 521 miles of levees. To these figures should now be added nearly 200,000 acres, as the reclamation of Colusa Basin has been practically completed, about 12,000 acres on the west side of the river opposite Sacramento City have been reclaimed, 90,000 acres, comprising the American Basin and other low lands east of the Sacramento and between the Bear and American Rivers, are in process of reclamation, and tentative plans are afoot for the reclaiming of 60,000 acres within Sutter Basin.

Immense levees, practically impregnable, now skirt the Feather River from Vernon to a point near Marysville, and on the south side of the Bear River from its mouth to a point near Wheatland. These levees will not only confine the flood waters of the Bear and Feather Rivers, but will result in a reduction of the time it formerly took them to reach the main stream.

During the floods of 1907 and 1909 the overflow waters of the Feather, Yuba, and Bear Rivers escaped freely into Butte, Sutter, and American Basins, which not only tended to flatten out the flood wave of the Feather River below the mouth of the Bear, but delayed its approach to the mouth of the American River until the crest of the flood wave of this stream had passed into the Sacramento below Sacramento City.

Under present conditions it is estimated that flood water in the lower Feather River will reach the mouth of the American at least two hours earlier than heretofore, provided, of course, that it is not drawn off into Yolo Basin either by the breaking of the west side Sacramento River levees or through artificial by-passes of sufficient width and capacity to materially lower the water level in the main stream.













W. B. No. 499.

Issued March 26, 1913.

U. S. DEPARTMENT OF AGRICULTURE,  
WEATHER BUREAU.

BULLETIN 44.

THE CLIMATE OF SAN FRANCISCO.

Prepared under the direction of WILLIS L. MOORE, Chief U. S. Weather Bureau,

BY

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WASHINGTON:  
GOVERNMENT PRINTING OFFICE.  
1913.

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## LETTER OF TRANSMITTAL.

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UNITED STATES DEPARTMENT OF AGRICULTURE,  
WEATHER BUREAU, OFFICE OF THE CHIEF,  
*Washington, D. C., December 3, 1912.*

The honorable the SECRETARY OF AGRICULTURE.

SIR: I have the honor to transmit herewith a paper by Prof. A. G. McAdie, of the Weather Bureau, on the "Climate of San Francisco," and to recommend its publication as a Weather Bureau Bulletin, the edition to be 5,000 copies.

Very respectfully, your obedient servant,

WILLIS L. MOORE,  
*Chief United States Weather Bureau.*

Approved.

JAMES WILSON,  
*Secretary.*



# THE CLIMATE OF SAN FRANCISCO.

## INTRODUCTION.

San Francisco is in latitude  $37^{\circ} 48'$  N., longitude  $122^{\circ} 23'$  W. from Greenwich. The declination at the present epoch is  $18^{\circ}$  E. and the dip  $62^{\circ} 12'$ . The difference in time between San Francisco, Washington, and Greenwich is as follows:

San Francisco.	Washington.	Greenwich (mean civil time).
12 noon.....	15 hours (3 p. m.).	20 hours (8 p. m.)

When it is noon at San Francisco it is 9.29 a. m. at Honolulu; 3.37 a. m. of the next date at Hongkong; 4.04 a. m. at Manila, and 5.19 a. m. at Yokohama.

In standard time, San Francisco is 3 hours earlier than New York, 2 hours earlier than Chicago, and 1 hour earlier than Salt Lake City. There is a difference of 9 minutes and 32 seconds between mean local time at San Francisco and one hundred and twentieth meridian time, the latter being the time in common use.

The city is built on the northern end of a peninsula and, except on the southern side, is surrounded by water. The Golden Gate is the water passage connecting the Bay of San Francisco with the Pacific Ocean, and it forms the northern boundary of the city. The Bay of San Francisco, extending north and south at an average distance from the ocean of 7 miles, bounds the city on the east. The bay, including its northern extension, San Pablo Bay, has an area of 420 square miles, and the length of the shore line is approximately 100 miles. The depth of the water varies from 2 to 69 fathoms. The eastern boundary of the bay, known as the Contra Costa and Alameda shores, is for the most part low lying, the land rising gradually for a distance of a mile or more and then abruptly forming the Berkeley Hills. Farther east Mount Diablo rises to a height of 3,849 feet, the summit of which can be plainly seen from the hills of the city, although distant 32 miles.

In the bay there are many islands, the most prominent being Angel Island, Yerba Buena, and Alcatraz.

The northern shore line is rugged and the land rises abruptly from the water. The Sausalito Hills have an average elevation of 110 meters (360 feet), and back of these Mount Tamalpais, 14 miles distant from the city in an air line, reaches an elevation of 792 meters (2,596 feet).

San Francisco covers an area of 46.5 square miles. Within the city limits are numerous hills, varying in elevation from 46 meters (150 feet) to 286 meters (938 feet). The highest elevation is Mount Davidson, 938 feet; followed closely by Mount Sutro, formerly known as Blue Mountain, 920 feet; the South Twin, 919 feet, and the North Twin, 919 feet.

#### **HISTORY OF THE RECORDS.**

Thomas Tennent, Dr. G. H. Gibbons, Dr. T. M. Logan and Mr. John Pettee kept records of rainfall and temperature for many years, and through their labors it has become possible to compile tables of these data covering a period of 63 consecutive years, the record beginning September 1, 1849. The thermometers used were of the self-registering pattern and were exposed on the north side of building on supports 10 inches distant from the wall and 6 feet above the ground. The instruments were at a later date compared with Weather Bureau instruments and found to be approximately accurate. The rainfall records obtained by Mr. Tennent at the foot of Market Street cover a period of 22 years, from September, 1849, to December, 1871. A 3-inch gauge of the type known for many years as the Tennent gauge was used. The catch of this gauge was carefully compared with the catch of the 8-inch Weather Bureau gauge and the differences were found to be small. Official records began when the Signal Service Office was established in the old Merchants Exchange Building, the first observation being made February 2, 1871. The office was moved to the Phelan Building September 4, 1890, and to the Mills Building November 1, 1893. After the earthquake and fire of April 18, 1906, the office was reestablished in the new Merchants Exchange Building, now known as the Chamber of Commerce. From April 19 until September 30, 1906, observations of temperature and rainfall, pressure, wind direction, and sunshine were made at No. 3014 Clay Street.

The instruments are now exposed on the roof of the 14-story building at No. 431 California Street. The portion of the roof in use has a width of 122 feet and a depth of 62 feet. The anemometer cups are 204 feet above the street; the rain gauge is 191 feet and the instrument shelter 198 feet above the street.

The station elevation of the barometer is 147.3 feet above the reference plane or city base, which in turn is 8 feet above mean sea level. The actual elevation of the barometer is 207.5 feet above sea level or 52.2 feet higher than the level used as a station elevation.

Extra instruments are exposed on the floor of the Chamber of Commerce and in addition a continuous record of the outside, or street temperature, is obtained. There is also a kiosk in Union Square Park, near the corner of Stockton and Post Streets, with instruments for recording temperature, rainfall, percentage of saturation, and pressure.

**CONTROLLING FACTORS OF THE CLIMATE.**

A clearer understanding of the problems connected with the weather of San Francisco can be had by considering the general topography of the section, rather than that of the city itself. The entire district is one of marked contrasts in air drainage. Strong surface currents of air will at times flow in from the sea through the Gate toward the Great Valley, while at other times these currents will be reversed in direction. The factor that exerts the greatest influence in controlling the weather of the San Francisco Bay section is the proximity of the ocean. The factor of next importance is the prevailing drift of the surface air from sea to land during summer months and from land to sea during winter months. A third factor is the diversified topography favorable on the whole for local circulation and consequently so-called local climates. A fourth factor is the general pressure distribution over the northwestern portion of the continent and the North Pacific Ocean. In a normal winter the Aleutian low extends from latitude  $40^{\circ}$  N. to  $60^{\circ}$  N. and from longitude  $130^{\circ}$  W. to  $140^{\circ}$  E. Variations in the position and intensity of this low are found to bear definite relation to the amount and frequency of rain. During summer months the Aleutian low practically disappears. The continental high and also the Pacific high play important rôles in connection with the strong northwest winds of summer on the California coast. For a discussion of the general relations between wet and dry seasons and the displacements of pressure areas or centers of atmospheric action, the reader is referred to Bulletin L, "Climatology of California," or to the Monthly Weather Review, April, 1908, in an article entitled "Forecasting for the Pacific Coast."

**STORM FREQUENCY.**

Compared with other portions of the United States, the San Francisco Bay section has comparatively few storms. This is because most of the recognizable disturbances pass far north of this section. Except in winter very few low pressure areas move from the ocean across California, as nearly all the storms that enter the United States from the west pass far north of central California. Since 1850 there have been during the months of June, July, and August but 13 storms of the character mentioned above. During September, 14 such disturbances have been noted in the period of 63 years, and of these the most important was the storm of September 22-26, 1904. This storm is worthy of special mention as it stands unparalleled in the history of summer and early fall disturbances. In four days 5 inches of rain fell, whereas the normal rainfall for the whole month of September is 0.30 of an inch. The relative frequency of storms increases with the advent of winter. During October there have been 40 disturbances; during November 60; and during December,



January, and February about 200 per month for the total period of 63 years. Occasionally there will be a winter month without a single disturbance, as was the case in December, 1876, and February, 1864. March is a month of moderate frequency, April a month of occasional storms, and May of few storms.

### PRESSURE.

The annual sea-level pressure at San Francisco as deduced from records covering a period of 38 years, 1873 to 1911 (1906 missing), is 30.027 inches. The lowest sea-level pressure recorded is 29.10 inches, which occurred February 22, 1891. The next lowest pressure, 29.23 inches, occurred March 10, 1904. The highest sea-level pressure, 30.60 inches, occurred December 23, 1905. The absolute range is 1.50 inches, and the mean annual range, 0.85 of an inch. The pressure is lowest during the summer months, averaging 29.92 inches, and highest in the winter months, averaging 30.10 inches. The daily pressure is lowest about 5.30 p. m., with a second minimum at 4 a. m., and highest at 10 a. m., with a second maximum at 11 p. m.

### TEMPERATURE.

San Francisco has a comparatively small range of temperature. The annual mean, based upon records covering a period of 40 years, 1871 to 1911, and obtained from the mean of the daily maximum and minimum readings, is 13° C. (56° F.). A truer value determined from the 24-hourly readings for a period of 20 years, 1891 to 1910, is 12.6° C. (54.6° F.).

The departures from the mean are comparatively small in all months. The warmest month is September, with a mean of 15° C. (59.1° F.), and the coldest month, January, 9.6° C. (49.2° F.). The warmest month has practically the same departure above the mean as the coldest month has below. The annual amplitude is 5.5° C. (9.9° F.).

The monthly mean temperatures determined from hourly readings, 1891 to 1910, are:

Month.	Degrees centi- grade.	Degrees Fahren- heit.	Month.	Degrees centi- grade.	Degrees Fahren- heit.
January.....	9.6	49.2	July.....	13.6	56.4
February.....	10.7	51.3	August.....	13.9	57.0
March.....	11.1	52.1	September.....	15.0	59.1
April.....	12.1	53.8	October.....	14.7	58.5
May.....	13.1	55.7	November.....	12.9	55.2
June.....	13.5	56.3	December.....	10.1	50.2

The coldest month was January, 1890, when the mean temperature was 7.8° C. (46° F.), and the warmest month, September, 1889, when the mean was 18.3° C. (65° F.).

In an average year there are approximately 1,311 hours when the temperature is above 15.6° C. (60° F.); 4,111 hours when the tem-

perature is above  $12.8^{\circ}\text{C}$ . ( $55^{\circ}\text{F}$ .); and 7,625 hours, or about 87 per cent of the entire year, when the temperature exceeds  $10^{\circ}\text{C}$ . ( $50^{\circ}\text{F}$ .).

Differences between day and night temperatures are small. The warmest hour, 2 p. m., has a mean temperature of  $15.1^{\circ}\text{C}$ . ( $59.2^{\circ}\text{F}$ .). The coolest hour, 6 a. m., has a mean temperature of  $10.5^{\circ}\text{C}$ . ( $50.9^{\circ}\text{F}$ .).

The highest temperature ever recorded in San Francisco is  $38.3^{\circ}\text{C}$ . ( $101^{\circ}\text{F}$ .). This occurred September 8, 1904, during a prolonged period of warm weather. For 4 consecutive days maximum temperatures exceeded  $32.2^{\circ}\text{C}$ . ( $90^{\circ}\text{F}$ .). This was the warmest spell of which there is record in San Francisco. In the past 20 years there have been 27 days on which the temperature exceeded  $32.2^{\circ}\text{C}$ . ( $90^{\circ}\text{F}$ .); but with the exception noted above there has been no period of 3 consecutive days when this temperature has been exceeded.

The lowest temperature recorded since 1871 is  $-1.7^{\circ}\text{C}$ . ( $29^{\circ}\text{F}$ .), which occurred January 15, 1888. In the last 20 years the temperature has not fallen below  $0^{\circ}\text{C}$ . ( $32^{\circ}\text{F}$ .).

The following table gives the monthly and annual extremes of temperature, from 1871 to 1911, inclusive:

	Maximum.		Lowest maximum.		Minimum.		Highest minimum.	
	$^{\circ}\text{C}$ .	$^{\circ}\text{F}$ .	$^{\circ}\text{C}$ .	$^{\circ}\text{F}$ .	$^{\circ}\text{C}$ .	$^{\circ}\text{F}$ .	$^{\circ}\text{C}$ .	$^{\circ}\text{F}$ .
January.....	26	78	14	58	-1.7	29	8	46
February.....	27	80	16	60	.6	33	8	47
March.....	27	80	17	62	.6	33	10	50
April.....	31	88	17	63	2.0	36	9	49
May.....	36	97	21	70	6.0	42	10	50
June.....	38	100	19	67	8.0	46	12	53
July.....	37	98	19	66	8.0	47	12	54
August.....	33	92	20	69	8.0	46	12	54
September.....	38	101	20	69	8.0	47	12	53
October.....	34	94	22	72	7.0	45	12	53
November.....	28	83	18	64	3.0	38	10	50
December.....	22	72	15	59	1.0	34	7	44
All years.....	38	101	14	58	-1.7	29	12	54

The absolute range of temperature from 1871 to 1911 is  $40^{\circ}\text{C}$ . or  $72^{\circ}\text{F}$ .

#### SUNSHINE.

The amount of sunshine received at San Francisco is not as large as might be expected, but nevertheless compares favorably with that of other cities in the United States. The average number of hours in a year, based upon hourly records from 1894 to 1910, is 2,807, or 63 per cent of the possible. The average number of hours of sunshine for different months is:

	Hours.	Per cent of possible.		Hours.	Per cent of possible.
January.....	147	50	July.....	208	68
February.....	163	63	August.....	258	61
March.....	213	67	September.....	262	68
April.....	256	66	October.....	236	68
May.....	294	67	November.....	175	58
June.....	345	75	December.....	160	54

The following table, from the Report of the Chief of the Weather Bureau, 1910-11, gives the total hours of sunshine during the year 1910 at certain of the larger cities in the United States:

	Hours.	Per cent of possi- ble.		Hours.	Per cent of possi- ble.
Baltimore.....	2,838	63	New York.....	2,750	61
Boston.....	2,547	56	Philadelphia.....	2,545	57
Chicago.....	2,778	60	Pittsburgh.....	2,164	47
Cincinnati.....	2,668	58	St. Louis.....	2,530	56
Denver.....	3,232	72	San Francisco.....	3,019	66
Kansas City.....	2,946	66	Washington.....	2,659	59
New Orleans.....	3,151	71			

It is interesting to compare the number of hours of sunshine at Mount Tamalpais for a year with the number at San Francisco, 14 miles away. In 1910 the total number of hours of sunshine at Mount Tamalpais was 3,258, or 70 per cent of the possible; at San Francisco, 3,019 hours, or 66 per cent of the possible. The difference, amounting to 239 hours, equivalent to the total sunshine of an average month, shows how much sunshine is lost at San Francisco through the summer afternoon fog. The accompanying diagrams (figs. 7 & 8) illustrate the difference in sunshine at the lower and upper stations. In some years there is a difference of as much as 500 hours in the annual amounts of sunshine at the two stations. In some seasons the lower station receives more sunshine than the upper, the clouds forming and remaining on the mountain crest. The fogs can be seen to great advantage from the station at Mount Tamalpais. Many photographic studies of characteristic fog forms have been published in the Monthly Weather Review, the Climatology of California, and elsewhere. Some of the fogs are caused by the mixing of air streams of different temperatures and different vapor content. Some are caused by cooling due to elevation and some by excessive loss of heat by radiation. It is interesting to note that in some of the summer months San Francisco receives but 68 per cent of the possible sunshine, while at Mount Tamalpais more than 90 per cent is recorded.

THE WINDS.

The prevailing drift of the surface air along the California coast is from west to east. The charts of wind direction issued each month for the North Pacific show in detail the relative strength and frequency of the surface winds on the California coast. Briefly, the summer winds may be grouped as follows: West to northwest, 75 per cent; north to northeast, 4 per cent; east to southeast, 3 per cent; south to southwest, 3 per cent; and calms, 15 per cent. The winter

winds show a greater percentage of motion from the south. Southerly gales are not infrequent, and there is a common belief that southeast is the prevalent direction in winter months. This, however, is not true. West to northwest winds have a frequency of 30 per cent; north to northeast, 18 per cent; east to southeast, 17 per cent; south to southwest, 22 per cent; and calms, 13 per cent.

It is plain from the above figures that northwest is the predominant direction along the coast in the vicinity of San Francisco. Owing to the topography there are certain deflections and changes in the direction of the wind, especially through the Golden Gate from northwest to west or even west by south.

During certain portions of the year, especially May and June, the northwest wind attains a remarkably high velocity. In May, 1902, and May, 1903, memorable northwest gales occurred. The following table gives wind data as recorded at Point Reyes Light, California:

Two memorable northwest gales at Point Reyes Light, Cal.

Date.	Average velocity, miles per hour.				Daily movement.		Maximum velocity.	Extreme velocity.	Time of maximum velocity.
	0 to 6 a. m.	6 a. m. to 12 noon.	12 noon to 6 p. m.	6 p. m. to 12 mid- night.	Total.	Average hourly.			
1902.									
May 13.....	7	4	11	10	Miles. 188	Miles. 8	Miles. 16	Miles. 16	.....
14.....	11	14	12	22	347	14	28	30	.....
15.....	29	31	31	36	756	31.5	45	50	.....
16.....	39	38	46	58	1,086	45	76	80	10.30 p. m.
17.....	64	54	67	78	1,580	66	90	96	7.00 p. m.
18.....	75	70	79	88	1,876	78	110	120	8.50 p. m.
19.....	59	45	59	64	1,360	57	75	80	7.00 p. m.
20.....	40	27	31	52	905	38	57	62	10.45 a. m.
21.....	34	12	11	22	474	20	48	50	12.50 a. m.
22.....	21	7	9	12	291	12	27	29	.....
23.....	17	7	10	15	287	12	26	30	.....
1903.									
May 13.....	13	9	11	35	410	17	48	50	10.15 p. m.
14.....	51	39	47	55	1,153	48	64	66	9.00 p. m.
15.....	43	44	63	78	1,371	57	89	93	7.55 p. m.
16.....	72	60	65	82	1,673	70	94	98	9.55 p. m.
17.....	62	42	51	67	1,339	56	89	92	12.05 a. m.
18.....	58	52	48	59	1,247	52	68	70	12.10 a. m.
19.....	45	45	47	50	1,124	47	60	62	12.15 a. m.
20.....	42	42	50	50	1,108	46	58	60	3.50 a. m.
21.....	47	47	53	57	1,227	51	64	66	8.45 a. m.
22.....	42	39	39	45	966	41	59	61	11.30 a. m.
23.....	47	19	18	30	679	28	52	54	12.45 a. m.

The following table gives comparative wind data for the gale of May, 1903; also the total movement for the month at five points in the vicinity of San Francisco. The table has especial interest because the grouping of the stations is such as to throw light on the movement of the air at the ocean level free from obstruction; at sea level near the entrance to the Gate; in the city itself on the roof of a high

building; on a headland 149 meters (490 feet), and on a mountain summit 721 meters (2,375 feet):

Stations.	Elevation.		Total for month.	Average daily.	Greatest in 24 hours.	Greatest hourly movement.
	Meters.	Feet.	Miles.	Miles.	Miles.	Miles.
Point Reyes Light.....	149	490	24,072	776	1,673	88
Mount Tamalpais.....	721	2,596	16,871	544	1,189	78
San Francisco.....	63	207	10,040	324	517	34
Point Lobos.....	76	250	15,431	498	929	60
S. E. Farallon Island.....	9	30	17,331	550	1,185	58

There is another class of high winds experienced at San Francisco, namely, the north-northeast winds of November, December, and occasionally January. These winds are different from the northwest winds of summer and are distinctly mountain winds. The highest wind velocity recorded in San Francisco, 64 miles from the northeast, occurred on November 30, 1906.

The most prevalent high wind of winter is from the southwest, closely followed by the southeast. The latter is the well-known wind preceding winter storms in this section. At San Francisco southeast winds will sometimes prevail for several days; but in most storms the wind after blowing for 12 or more hours increases in velocity to 40 miles an hour, more or less, and then shifts suddenly to the southwest, attaining a slightly higher velocity. After a few hours the velocity decreases and, with the change to northwest, the weather clears. At such times the air is remarkably pure and the distant mountains can be seen distinctly.

The average hourly wind velocity in San Francisco is nearly 10 miles and the prevailing direction west. The wind attains its greatest velocity about 4.30 p. m. and its least about 6 a. m. The average movement during the 12 hours from 7 a. m. to 6 p. m. is approximately 11 miles per hour and from 7 p. m. to 6 a. m. 9 miles per hour.

FOG.

One of the most marked climatic features of San Francisco is the prevalence of fog. In summer afternoons sea fog moves through the Gate, appearing about 1 p. m. and covering the whole sky by 3 p. m. The average depth of the fog layer is 518 meters (1,700 feet). Comparing the percentage of possible sunshine at San Francisco and Mount Tamalpais, it is at once apparent that the summer afternoon sea fog shuts out 50 per cent or more of the possible sunshine between 3 and 7 p. m. during June, July, and August. There is also curtailment of sunshine between 7 and 9 a. m. during May, June, July, August, and September.

In winter, morning fogs, or, as they are commonly called "tule" fogs, frequently occur. These are low-lying banks of condensed vapor formed by cooling due to radiation and contact. The land surfaces are much cooler than the water surfaces, and hence these fogs have a decided motion from the land to the sea. The average number of foggy days is 24 per year.

For a detailed description of fog phenomena in the vicinity of San Francisco the reader is referred to special articles in the Monthly Weather Review, the Climatology of California, and the Meteorological Charts of the North Pacific Ocean, 1911.

In addition to the summer afternoon sea fog, moving from west to east, and the land or tule fog of winter mornings, there is a third kind of fog which may be called smoke fog. Under certain atmospheric conditions the smoke of the city moves seaward during the forenoon and returns about 1 p. m. as a dense black pall. This is the cause of the so-called dark days. The phenomenon is of brief duration, seldom exceeding two hours; but while it lasts causes some apprehension.

#### HUMIDITY.

Relative humidity is a term frequently used in attempts to describe relative dampness of a locality. The term is misleading and while generally used can not give a proper basis for comparison unless temperatures are also given, inasmuch as relative humidity is only a ratio and does not indicate a fixed amount of water vapor. Thus at San Francisco relative humidity throughout the year is high; but during the summer months, owing to low temperatures, the absolute weight of water vapor per unit of volume and the vapor tension are much less than at coast stations of the Atlantic.

The following table shows mean vapor pressures and temperatures at San Francisco, New York, Chicago, and New Orleans:

San Francisco:	°F.
January...0.282 inch.....	49.5
July......384 inch.....	57.3
New York:	
January... .125 inch.....	30.2
July......588 inch.....	73.5
Chicago:	
January... .099 inch.....	23.7
July......548 inch.....	72.3
New Orleans:	
January... .316 inch.....	53.0
July......810 inch.....	81.3

This table explains why, notwithstanding high relative humidity in summer, the vapor tension and absolute humidity are low at San Francisco.

The highest relative humidity occurs in July, from 1 a. m. until 7 a. m., and equals or exceeds 95 per cent. The lowest relative humidity occurs in October, about 1 p. m., and is about 52 per cent. The vapor pressure is greatest in July, about 1 p. m., amounting to 0.410 inch. The vapor pressure is lowest in December, about 4 a. m., when it is less than 0.250 inch.

#### RAINFALL.

Rainfall records have been maintained in San Francisco for a period of 63 years. The greatest 24-hour rainfall occurred on January 28, 1881, when 4.67 inches fell. The next greatest 24-hour rainfall was on September 24, 1904, when 3.58 inches fell. A detailed statement of excessive rains will be found elsewhere. The longest rainless period was in 1903, when no rain fell from April 16 until October 9, 175 days. In 1911 there was no rain from June 6 to October 1, 116 days.

Some of the months of heaviest rain were: January, 1862, when 24.36 inches of rain fell, and 18 days of the month were rainy. In January, 1911, 13.79 inches fell, distributed over 18 days. In January, 1909, 10.51 inches fell, but there were 26 rainy days, making it in this sense the rainiest month known at San Francisco. In January, 1890, 9.61 inches fell, and there were 23 rainy days. In January, 1907, there were 21 rainy days, but the total rainfall amounted to only 4.41 inches, which is less than a normal rainfall, notwithstanding that the number of rainy days was nearly double the normal.

The rainiest February was in 1878, when 12.52 inches fell on 19 days. In February, 1887, 9.24 inches fell and there were 16 rainy days. In February, 1891, 7.26 inches fell and there were 19 rainy days; in February, 1902, 7.27 inches fell and there were 19 rainy days; in February, 1909, 7.53 inches fell and there were 18 rainy days.

The rainiest March was in 1879, when 8.75 inches fell and there were 14 rainy days; in 1907 the rainfall amounted to 8.42 inches and there were 20 rainy days; in 1904, the rainfall amounted to 6.01 inches and there were 23 rainy days; in 1884, 8.24 inches fell and there were 16 rainy days.

The rainiest April was in 1880, when 10.06 inches fell and there were 17 rainy days. The average number of rainy days in April is 6, and the average rainfall 1.64 inches.

From May until October, inclusive, there is little rain.

The rainiest November was in 1885, when 11.78 inches fell and there were 19 rainy days. The average number of rainy days in November is 7.

The rainiest December was in 1866, when 15.16 inches fell and there were 18 rainy days; in December, 1889, 13.81 inches fell and



there were 24 rainy days; in December, 1880, 12.33 inches fell and there were 19 rainy days.

*Number of rainy days in the year.*—In the past 62 years, 1850 to 1911, there have been 4,207 rainy days. The yearly distribution is: January, 11; February, 10; March, 11; April, 6; May, 4; June, 1; July, 0; August, 0; September, 2; October, 4; November, 7; December, 11. For the year, average number 67.

### MONTHLY RAINFALL.

#### JANUARY.

From records covering a period of 63 years, 1850 to 1912, the mean January rainfall is 4.90 inches. The greatest rainfall was in 1862, when 24.36 inches fell and the least was in 1852, when 0.58 of an inch fell. There were 5 years in which the rainfall exceeded 10 inches and 3 years in which the rainfall did not exceed 1 inch. The largest number of rainy days, 23, occurred in 1890 and the smallest number in 1852, when there were 4 rainy days. The average number of rainy days is 11. There have been 16 Januarys when the number of rainy days equaled or exceeded 15. In January, 1859, there were 26 consecutive days of fair weather.

#### FEBRUARY.

The mean rainfall is 3.55 inches. Reduced to a 30-day normal, best obtained by eliminating the rainfall of leap years and adding twice the rainfall on the 14th, we have 3.81 inches. The average number of rainy days is 10. The heaviest February rainfall was 12.52 inches in 1878 and the least, no rain, in 1864. Rainfalls exceeding 10 inches occurred once, in 1878, and rainfalls of less than 1 inch occurred 13 times. The largest number of rainy days in any February was 19, which occurred in 1878, 1891, and 1902. There have been 11 Februarys when the number of rainy days did not exceed 5. The largest number of consecutive rainy days was 15, which occurred in 1891. The largest number of consecutive fair days was in February, 1864, when there were 29.

#### MARCH.

The mean rainfall is 3.36 inches. The greatest amount was in 1879, when 8.75 inches fell. The next rainiest March was in 1907, when 8.42 inches fell. The least was in 1898, when only 0.24 of an inch fell. There have been 12 years in which the rainfall for March equaled or exceeded 5 inches, and 8 in which the total monthly amount did not exceed 1 inch. In 1908 there were 18 consecutive days without rain, and in 1911, 21 days, with exception of a trace on one day. In 1900 there were 23 consecutive days during which



only a trace of rain fell. In 1875 there were 17 consecutive fair days, and in 1877, 21 consecutive fair days. In 1861 the month was without rain until the 23d. The average number of rainy days is 10. The largest number of rainy days in any month was in 1904 when there were 23, of which 19 were consecutive. The smallest number of rainy days was in 1901 when there were only 3. The heaviest 24-hour rainfall occurred on March 5, 1879, when 3.31 inches fell.

#### APRIL.

The mean rainfall is 1.64 inches. The month of heaviest rainfall was in 1880, when 10.06 inches were measured. There have been 6 Aprils out of the past 63 in which the rainfall equaled or exceeded 5 inches. There have been 27 in which the amount of rain did not exceed 1 inch. No rain fell in April, 1857, and there was only a trace of rain during April, 1909. The largest number of consecutive rainy days occurred in 1880, when it rained for 11 days. The average number of rainy days in April is 6. The greatest 24-hour rainfall was 2.43 inches on April 24, 1896.

#### MAY.

The mean rainfall for May is 0.73 of an inch. The rainiest May was in 1883, when 3.52 inches fell. There have been 5 Mays during the past 63 years when practically no rain fell. During 18 years the rainfall for May exceeded 1 inch. The average number of rainy days is 4. The greatest number of consecutive rainy days was 5, which occurred in 1860, 1889, and 1906. The largest number of rainy days in April was 11, in 1860 and 1883. The greatest 24-hour rainfall, 1.29 inches, occurred on May 5, 1889.

#### JUNE.

The mean rainfall for June for a period of 62 years is 0.16 of an inch. The month is practically rainless, only 3 times has the rainfall exceeded 1 inch. The heaviest June rainfall occurred in 1884, when 2.57 inches fell. The average number of rainy days is 2. In 1888 there were 9 rainy days. The heaviest 24-hour rainfall occurred on June 12, 1884, when 1.23 inches fell. Of the past 62 years 20 have been without rain during the month of June and 27 have had a rainfall not exceeding 0.01 of an inch.

#### JULY.

The mean rainfall for July is 0.02 of an inch. In the past 62 years there have been only 3 showers in which the total amount exceeded 0.05 of an inch. Most of the rainfalls did not exceed 0.01 of an inch. The greatest 24-hour rainfall was 0.23 of an inch on July 16, 1886.

## AUGUST.

August, like July, is practically a rainless month. The mean rainfall is 0.02 of an inch. There has never been an August when the total rainfall exceeded 0.25 of an inch. Only 14 of the 62 months under consideration have had a rainfall exceeding 0.01 of an inch. The greatest 24-hour rainfall was 0.12 on August 26, 1858.

## SEPTEMBER.

The mean rainfall is 0.30 of an inch. This, however, is larger than might be expected and is caused by phenomenal rainfall in September, 1904. In the 5 days, 22d to 26th, more than 5 inches of rain fell. The average number of rainy days is 2. The greatest number of consecutive rainy days is 5. There have been 19 Septembers without rain. Only once has the rainfall exceeded 5 inches and only 4 times has it exceeded 1 inch. The greatest 24-hour rainfall, 3.09 inches, occurred on September 23, 1904.

## OCTOBER.

The mean rainfall is 1.02 inches. The heaviest rainfall was in 1889, when 7.28 inches fell. Other rainy Octobers were, 1899, 3.92 inches; 1876, 3.36 inches; and 1849, 3.14 inches. There have been 9 Octobers without rain. The average number of rainy days is 4, and the greatest number, 13, occurred in 1889. The heaviest 24-hour rainfall, 2.06 inches, occurred on October 21, 1858.

## NOVEMBER.

The mean rainfall is 2.55 inches. The heaviest rainfall was in 1885, when 11.78 inches fell. Other rainy Novembers were, 1849, when 8.66 inches fell; 1859, when 7.28 inches fell. November, 1890, was without rain. The rainfall for November was less than 1 inch in 21 years. The average number of rainy days is 7. The greatest number of rainy days was 19 in 1885. The greatest 24-hour rainfall, 3.98 inches, fell on November 26, 1864, and again on November 23, 1874.

## DECEMBER.

The mean rainfall is 4.56 inches. The heaviest rainfall was in 1866, when 15.16 inches fell. Other rainy Decembers were, 1852, 13.20 inches; 1871, 14.36 inches; 1880, 12.33 inches; 1889, 13.81 inches, and 1894, 9.01 inches. December, 1876, was rainless. Less than an inch of rain fell in 1854, 1865, 1874, 1878, 1883, and 1901. The average number of rainy days is 11. The greatest number, 24, was in 1889. The greatest 24-hour rainfall, 4.28 inches, fell on the 19th, 1866.

In connection with the absence of rain during December, 1876, it may be noted that there was no rain between November 16, 1876, and January 16, 1877. Or, in other words, there was a period of 60 consecutive days without rain in midwinter.

#### THUNDERSTORMS.

Few thunderstorms occur at San Francisco. In the past 20 years there have been 28, but not a single one that could be considered as severe. The following table shows the distribution: January, 2; February, 3; March, 1; April, 3; May, 1; June, 1; July, 1; August, 2; September, 2; October, 3; November, 3; and December, 6. The greatest number recorded in any one year was 8, in 1906. During the past 20 years there have been 8 years without record of a thunderstorm. The storms are mild in character, the lightning flashes of moderate intensity, and the thunder usually limited to a few peals. Damage from lightning is practically unknown, although some flagpoles have been shattered and one or two trees struck in the past 60 years.

#### HAIL.

There have been 56 hailstorms in the past 20 years. January and December are the months of maximum frequency. There is no record of any hailstorm occurring during June, July, August, and September.

#### SNOWSTORMS.

Snow is of rare occurrence. During winter storms the tops of the hills in the southwestern portion of the city are occasionally whitened by snowflakes. These melt rapidly and snow of appreciable depth is rare. However, snow can be seen frequently during winter months on Mount Tamalpais, Mount Diablo, and the peaks of the Mount Hamilton Range. The heaviest snowfall in the Bay Section occurred January 9, 1913, when Mount Tamalpais and Angel Island were covered.

#### DATES OF SNOWFALL AT SAN FRANCISCO SINCE MARCH 1, 1871.

January 21, 1876.—Light snow fell for ten minutes.

December 31, 1882.—Heavy snow fell from 11.30 a. m. to 4.20 p. m., amount 3.5 inches.

February 6, 1883.—A few flakes of snow fell during the day.

February 7, 1884.—Snow fell at intervals during the day, depth varying from 1 to 2 inches.

February 5, 1887.—Snow fell during the day; depth at office 3.7 inches, while in the western portion of the city it was fully 7 inches deep.

January 4, 1888.—A few flakes of snow fell during the day.

January 16, 1888.—Light snow fell to the depth of 0.1 inch.

March 2, 1894.—A few flakes of snow fell during the day.

March 2, 1896.—Snow mixed with rain fell at intervals during the day.

March 3, 1896.—Heavy snow fell during the night; depth at office at 8 a. m. 0.5 inch.

February 3, 1903.—Snow, large flakes, 11.16 to 11.20 a. m.  
March 5–6, 1908.—Trace of snow fell.  
February 26 and 27, 1911.—0.04 of an inch of snow fell.  
January 9, 1913.—Light snow fell, which melted quickly.

TABLE 1.—Annual sea-level pressure at San Francisco.

Year.	Inches.	Year.	Inches.	Year.	Inches.
1873.....	30.027	1886.....	30.026	1899.....	30.053
1874.....	30.018	1887.....	30.023	1900.....	30.043
1875.....	30.024	1888.....	29.998	1901.....	30.050
1876.....	30.004	1889.....	29.998	1902.....	29.939
1877.....	29.992	1890.....	30.035	1903.....	30.058
1878.....	29.968	1891.....	30.036	1904.....	30.060
1879.....	30.017	1892.....	30.032	1905.....	30.025
1880.....	30.031	1893.....	30.055	1906.....	.....
1881.....	30.028	1894.....	30.058	1907.....	30.024
1882.....	30.045	1895.....	30.043	1908.....	30.038
1883.....	30.039	1896.....	30.041	1909.....	30.019
1884.....	29.985	1897.....	30.055	1910.....	30.054
1885.....	30.012	1898.....	30.047	1911.....	30.033

Mean of 38 years, 30.027 inches.

TABLE 2.

This table gives the highest temperature for each month from 1871 to 1912, as given by self-registering mercurial thermometer.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Absolute annual maxi- mum.
1871.....	.....	.....	74	69	76	77	66	69	78	84	78	62	84
1872.....	61	64	64	71	81	92	70	77	82	80	67	62	92
1873.....	66	64	73	75	75	67	74	72	69	79	72	59	79
1874.....	61	62	62	72	83	82	73	71	89	78	69	62	89
1875.....	62	63	67	81	71	79	71	70	82	79	68	65	82
1876.....	58	67	70	75	81	93	76	78	86	72	70	64	93
1877.....	69	67	73	64	75	92	76	75	92	81	69	64	92
1878.....	62	65	66	70	78	73	73	73	78	78	68	68	78
1879.....	62	70	77	76	75	85	76	89	86	81	65	64	89
1880.....	60	62	66	69	84	82	73	73	79	78	75	61	84
1881.....	63	69	76	76	75	71	83	70	80	72	66	63	83
1882.....	60	61	73	74	74	68	73	69	83	76	64	65	83
1883.....	60	70	74	63	86	95	80	82	91	74	67	62	95
1884.....	58	71	68	68	80	71	83	75	73	76	70	64	83
1885.....	62	69	76	75	77	67	78	81	87	76	70	67	87
1886.....	68	71	73	79	86	83	78	85	94	79	75	66	94
1887.....	73	67	78	78	97	90	70	74	89	87	74	69	97
1888.....	63	76	74	88	81	80	93	85	88	87	74	65	93
1889.....	64	75	79	77	88	75	83	80	89	87	77	63	89
1890.....	59	64	70	81	85	81	80	85	81	86	78	60	86
1891.....	72	63	76	81	75	100	81	92	86	85	78	64	100
1892.....	66	66	80	68	90	73	90	92	88	79	78	64	92
1893.....	60	69	78	72	74	90	74	72	72	74	74	72	90
1894.....	58	62	66	82	72	69	76	91	94	89	79	61	94
1895.....	63	69	70	73	89	86	83	80	89	83	83	60	89
1896.....	63	72	72	66	91	79	72	72	81	85	66	64	91
1897.....	60	66	63	84	88	83	82	70	92	85	68	63	92
1898.....	59	70	74	87	63	89	88	72	80	81	78	66	89
1899.....	78	80	74	80	80	75	73	78	73	94	65	63	94
1900.....	64	68	71	69	71	74	73	82	92	83	79	63	92
1901.....	62	75	78	72	81	82	75	72	78	91	75	72	91
1902.....	58	65	68	78	70	73	77	82	83	77	67	62	83
1903.....	59	66	64	71	77	96	91	77	92	85	67	66	96
1904.....	65	60	66	84	86	90	73	75	101	79	74	61	101
1905.....	63	71	79	71	85	67	98	73	87	84	74	67	98
1906.....	68	71	74	76	72	82	82	76	82	86	77	61	86
1907.....	61	68	69	81	80	85	78	74	78	90	78	68	90
1908.....	64	65	76	85	79	86	77	80	89	82	74	61	89
1909.....	60	62	67	80	80	94	77	82	93	86	74	63	94
1910.....	59	64	77	87	90	74	76	79	82	89	76	68	90
1911.....	72	67	79	73	85	77	84	79	82	87	77	71	87
1912.....	65	68	67	66	87	93	71	77	94	81	.....	.....	.....

TABLE 3.

This table gives the lowest temperature for each month from 1871 to 1912, as given by self-registering alcohol thermometer.

1871	45	45	46	48	50	51	53	51	46	42
1872	43	47	48	48	52	52	53	52	48	41
1873	46	40	45	43	48	50	52	54	49	44
1874	39	43	42	47	50	48	49	51	50	44
1875	39	43	42	40	49	49	52	50	52	49
1876	36	41	41	44	45	49	51	51	52	50
1877	42	46	47	46	48	51	53	52	51	49
1878	39	45	46	44	48	51	51	52	52	47
1879	40	44	47	46	46	49	51	50	52	49
1880	37	38	39	42	45	49	52	51	50	41
1881	44	45	40	48	49	50	49	52	50	45
1882	40	38	41	44	45	49	52	50	50	48
1883	36	35	44	43	48	51	50	52	53	48
1884	43	36	45	45	48	52	52	52	50	50
1885	43	46	50	47	50	50	54	52	52	53
1886	41	41	41	44	48	48	50	48	50	46
1887	42	33	45	44	46	48	49	49	50	49
1888	29	42	38	46	47	53	51	51	50	47
1889	40	39	47	49	48	52	50	49	51	51
1890	38	36	41	46	47	49	49	50	52	48
1891	39	40	43	40	48	48	50	50	51	48
1892	40	42	42	44	47	47	50	50	51	47
1893	36	39	40	40	46	47	47	47	50	47
1894	36	38	37	42	44	47	48	49	48	46
1895	38	41	40	44	48	48	50	50	51	48
1896	40	44	33	41	45	47	50	52	52	47
1897	40	38	39	45	47	48	47	49	50	48
1898	38	43	40	44	46	49	47	47	50	50
1899	40	34	42	43	43	47	48	50	48	48
1900	42	44	43	45	47	47	48	50	47	48
1901	37	38	44	41	46	47	47	49	50	49
1902	38	40	41	44	47	48	47	52	51	49
1903	37	37	41	43	46	48	48	46	50	51
1904	40	40	40	44	45	48	50	49	49	52
1905	40	42	42	49	48	49	49	50	51	49
1906	41	46	41	43	42	48	49	50	48	47
1907	36	43	38	45	47	48	50	51	53	51
1908	40	40	40	45	46	46	48	50	47	44
1909	38	42	41	44	44	47	49	49	50	49
1910	36	38	44	46	48	48	48	48	47	44
1911	41	38	42	42	46	47	49	49	50	43
1912	40	44	43	44	46	48	49	50	48	42

TABLE 4.—Mean hourly temperatures in degrees Fahrenheit, 1891-1910.

Hours.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1 a. m.	48	50	50	51	52	53	53	54	56	56	53	49	50.2
2 a. m.	47	49	50	50	52	52	53	54	56	55	53	48	51.7
3 a. m.	47	49	49	50	51	52	53	54	56	55	52	48	51.4
4 a. m.	47	48	49	50	51	52	53	54	56	55	52	48	51.3
5 a. m.	47	49	49	50	51	52	53	54	56	55	52	48	51.3
6 a. m.	46	48	49	50	51	52	53	54	55	55	52	47	50.9
7 a. m.	46	48	49	50	52	54	54	54	56	55	52	47	51.4
8 a. m.	46	48	50	52	54	56	55	56	57	56	52	47	52.4
9 a. m.	47	49	51	54	56	58	57	57	59	57	53	48	53.8
10 a. m.	48	50	52	56	57	60	59	59	61	59	54	49	55.4
11 a. m.	49	52	54	57	59	61	60	60	63	61	56	50	56.8
12 noon.	50	53	55	58	59	61	61	61	64	63	59	52	58.0
1 p. m.	51	55	56	59	60	62	61	62	65	64	59	53	58.8
2 p. m.	52	56	57	59	60	62	62	62	65	64	60	54	59.3
3 p. m.	53	56	57	59	60	61	61	62	64	64	60	54	59.1
4 p. m.	53	56	58	58	59	60	60	61	63	63	59	54	58.4
5 p. m.	52	55	55	57	58	60	59	60	62	61	58	53	57.5
6 p. m.	52	54	54	56	57	58	58	58	60	60	57	52	56.4
7 p. m.	51	53	53	54	55	57	56	57	59	59	57	52	55.3
8 p. m.	50	52	53	54	54	55	55	56	58	58	56	51	54.5
9 p. m.	50	52	52	53	54	55	55	56	58	58	56	50	53.3
10 p. m.	49	51	51	52	53	54	54	55	57	57	55	50	53.3
11 p. m.	49	50	51	52	53	53	54	55	57	57	54	50	52.8
Midnight.	48	50	50	51	52	53	54	54	56	56	54	49	52.4
Mean.	49.2	51.3	52.1	53.8	55.7	56.3	56.0	57.0	59.1	58.5	55.2	50.2	54.6

**NOTE ON EXPOSURE OF ANEMOMETERS AT SAN FRANCISCO.**

The elevations of the anemometer above ground (street) have been as follows: January 1, 1891, to November 1, 1892, 109 feet; November 1, 1892, to April 18, 1906, 167 feet; May 1, 1906, to September 30, 1906, 42 feet; October 1, 1906, to September 31, 1910, 204 feet.

These elevations, however, can not be used without explanation concerning elevation of cups above the roof or nearest deck surface. Unfortunately most of the roofs occupied have had on them platforms or raised surfaces, and, as in the case of the Mills Building, the platform serving as a deck for Weather Bureau instruments was itself on top of an extra story 14 feet in height. This superstructure was 10 feet from the west wall of the building and about 30 feet from the south wall.

In the Mills Building and the Merchants Exchange are large interior courts, or light wells, which may have affected the results.

The approximate heights of the cups above the roof proper are: Merchants Exchange, October 1, 1906, to December 31, 1910, 18 feet; Mills Building, November 1, 1892, to April 18, 1906, 30 feet; Phelan Building, January 1, 1891, to November 1, 1892, 12 feet; No. 3014 Clay Street, May 1, 1906, to September 30, 1906, 4 feet.

**TABLE 5.—Average hourly wind velocity in miles.**

[Period. 1891-1910.]

Hours.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1 a. m.	6.4	6.3	7.2	7.4	8.6	9.5	10.0	9.5	7.6	6.5	5.6	5.9	7.5
2 a. m.	6.4	6.1	6.9	7.1	8.0	9.0	9.5	9.0	7.1	5.6	5.6	6.0	7.2
3 a. m.	6.4	5.8	6.8	6.7	7.4	8.3	8.8	8.2	6.7	5.4	5.6	6.0	6.8
4 a. m.	6.4	5.9	6.6	6.3	7.1	7.7	8.4	8.0	6.2	5.3	5.5	6.1	6.6
5 a. m.	6.5	5.9	6.6	6.3	7.0	7.4	8.0	7.7	6.0	5.1	5.5	6.2	6.5
6 a. m.	6.5	5.8	6.5	6.1	6.8	7.1	7.8	7.3	5.8	5.0	5.5	6.4	6.4
7 a. m.	6.7	5.9	6.4	7.3	6.8	7.0	7.8	7.2	5.8	5.0	5.5	6.5	6.5
8 a. m.	6.9	6.2	6.8	6.9	7.3	7.6	8.1	7.5	6.0	5.3	5.7	6.6	6.7
9 a. m.	7.2	6.7	7.3	7.6	7.8	8.1	8.4	7.8	6.5	5.6	5.9	6.9	7.2
10 a. m.	7.6	7.2	7.9	8.2	8.7	9.3	9.3	8.8	7.1	6.1	6.3	7.2	7.8
11 a. m.	7.8	7.4	8.4	9.2	10.4	11.4	11.2	10.5	8.3	6.5	6.5	7.3	8.8
12 noon.	7.9	7.6	9.2	10.3	12.7	14.4	14.2	12.9	10.5	7.6	6.8	7.4	10.1
1 p. m.	8.2	8.3	10.6	13.2	15.0	16.9	16.9	15.7	12.9	9.8	7.3	7.7	11.8
2 p. m.	8.6	9.3	12.0	14.8	16.4	18.9	19.1	18.0	15.3	11.2	8.2	7.7	13.3
3 p. m.	8.5	10.1	13.2	15.7	17.5	20.0	20.6	19.6	16.7	12.6	8.9	7.7	14.3
4 p. m.	8.4	10.4	13.9	16.5	18.1	20.6	21.5	20.3	17.6	13.2	9.3	7.6	14.8
5 p. m.	8.1	10.4	13.6	16.6	18.1	20.8	21.8	20.5	17.8	13.7	9.6	7.2	14.8
6 p. m.	7.8	9.9	13.0	16.0	17.7	20.2	21.1	19.8	17.2	13.0	9.1	7.1	14.3
7 p. m.	7.6	9.3	11.9	14.6	16.1	18.7	19.5	18.2	15.2	11.2	8.2	6.5	13.1
8 p. m.	7.2	8.7	10.7	12.8	14.4	16.8	17.4	16.3	13.2	9.6	7.6	6.3	11.8
9 p. m.	7.0	7.8	9.4	11.0	12.7	14.7	15.3	14.3	11.5	8.5	6.9	6.2	10.4
10 p. m.	6.6	7.4	8.4	10.1	11.2	12.7	13.7	12.5	10.3	7.6	6.4	6.2	9.4
11 p. m.	6.8	6.9	7.9	9.1	10.1	11.4	12.2	11.3	9.1	6.8	6.1	6.1	8.6
12 midnight.	6.3	6.4	7.4	8.1	9.2	10.2	11.0	10.2	8.2	6.3	5.8	6.0	7.9
Average...	7.2	7.6	9.1	10.3	11.5	12.9	13.4	12.5	10.3	8.0	6.8	6.7	9.7

## THE CLIMATE OF SAN FRANCISCO.

**TABLE 6.**—*Mean velocity of wind, San Francisco.*

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1891.....	4.5	8.6	7.9	8.8	10.0	11.0	11.7	10.6	9.5	7.3	4.3	6.4
1892.....	4.5	5.7	7.3	9.0	9.0	11.7	12.0	10.4	9.2	6.7	9.1	9.2
1893.....	10.0	8.4	10.1	12.4	12.2	15.3	15.3	14.5	12.6	9.3	7.7	6.0
1894.....	8.0	9.9	11.0	11.9	12.7	14.2	15.1	13.9	11.9	9.0	5.3	9.0
1895.....	9.5	7.1	9.6	10.7	13.0	14.3	15.5	13.8	11.5	8.7	7.7	7.3
1896.....	9.5	7.0	8.4	11.6	12.4	14.3	14.1	13.9	10.9	9.6	7.9	7.7
1897.....	6.8	9.4	11.3	11.3	13.5	13.6	14.3	14.1	11.8	9.7	7.4	6.7
1898.....	7.5	8.3	10.4	12.3	13.3	13.0	15.8	14.6	11.9	7.6	7.4	6.9
1899.....	7.9	8.7	9.8	11.7	13.9	14.2	15.3	14.4	12.6	8.5	6.6	8.6
1900.....	7.2	7.2	10.0	11.8	12.1	14.3	14.5	13.1	10.9	8.3	6.9	7.3
1901.....	7.5	6.6	11.8	11.8	12.5	13.9	14.5	13.1	11.0	8.3	6.4	6.6
1902.....	7.6	10.0	9.7	10.7	12.9	13.9	13.1	12.2	10.8	8.5	8.0	6.0
1903.....	7.6	7.3	7.8	10.7	13.5	14.9	13.3	13.4	10.2	8.0	7.8	5.6
1904.....	5.8	8.0	9.6	9.1	12.0	13.1	14.2	13.0	9.9	7.4	5.3	6.6
1905.....	5.9	6.4	10.3	10.5	10.9	14.0	12.4	12.0	10.2	7.6	8.1	6.0
1906.....	7.3	6.6	8.5	10.2	7.0	7.1	9.2	8.8	7.1	7.6	8.7	6.7
1907.....	8.0	5.4	8.4	6.8	8.8	9.5	11.7	10.5	8.6	6.6	4.8	6.2
1908.....	5.6	6.4	6.2	8.1	8.8	10.7	11.8	11.1	8.7	7.3	5.7	5.1
1909.....	10.1	7.8	7.4	8.3	11.1	12.2	11.7	11.5	8.3	6.5	5.4	6.1
1910.....	5.3	6.9	7.0	8.2	9.1	11.9	12.5	11.9	9.2	6.6	5.7	4.2
Means....	7.24	7.58	9.1	10.3	11.5	12.9	13.4	12.5	10.3	8.0	6.8	6.7

<sup>1</sup> Elevation of anemometer changed from 167 to 42 feet on May 1, and to 204 feet Oct. 1, 1936.

**TABLE 7.**—*Prevailing hourly wind direction.*

[illegible]



TABLE 8.—San Francisco rainfall, monthly, seasonal, and annual, 1849–1912.

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Seasonal.	Year.	Annual.
1849–50.....	0	0	0	3.14	8.66	6.20	8.34	1.77	4.53	0.46	0	0	33.10	1850	17.40
1850–51.....	0	0	0.33	0	0.92	1.06	0.72	0.54	1.94	1.23	0.67	0.02	7.42	1851	15.00
1851–52.....	0	0.02	1.03	0.21	2.12	7.10	0.58	0.14	6.68	0.26	0.32	0	18.46	1852	27.29
1852–53.....	0	0	0	0.80	5.31	13.20	3.92	1.42	4.86	5.37	0.38	0	35.26	1853	21.17
1853–54.....	0	0.04	0.46	0.12	2.28	2.32	3.88	8.04	3.51	3.12	0.02	0.08	23.87	1854	22.45
1854–55.....	0	0.01	0.15	2.43	0.34	0.87	3.67	4.77	4.64	5.00	1.88	0	23.76	1855	26.39
1855–56.....	0	0	0	0	0.67	5.76	9.40	0.50	1.60	2.94	0.76	0.03	21.66	1856	22.31
1856–57.....	0.02	0	0.07	0.45	2.79	3.75	2.45	8.59	1.62	0	0.05	0.12	19.91	1857	20.96
1857–58.....	0	0.05	0	0.93	3.01	4.14	4.36	1.83	5.55	1.55	0.34	0.05	21.81	1858	23.46
1858–59.....	0.05	0.16	0	2.74	0.69	6.14	1.28	6.32	3.02	0.27	1.55	0	22.22	1859	21.39
1859–60.....	0	0.02	0.03	0.05	7.28	1.57	1.64	1.60	3.99	3.14	2.86	0.09	22.27	1860	21.18
1860–61.....	0.21	0	0	0.91	0.58	6.16	2.47	3.72	4.06	0.51	1.00	0.08	19.72	1861	26.52
1861–62.....	0	0	0.02	0	4.10	9.54	24.36	7.53	2.20	0.73	0.74	0.05	49.27	1862	38.63
1862–63.....	0	0	0	0.52	0.15	2.35	3.63	3.19	2.06	1.61	0.23	0	13.74	1863	15.10
1863–64.....	0	0	0.03	0	2.55	1.80	1.83	0	1.52	1.57	0.78	0	10.08	1864	21.64
1864–65.....	0	0.21	0.01	0.13	6.68	8.91	5.14	1.34	0.74	0.94	0.63	0	24.73	1865	14.06
1865–66.....	0	0	0.24	0.26	4.19	0.58	10.88	2.12	3.04	0.12	1.46	0.04	22.93	1866	36.28
1866–67.....	0	0	0.11	0	3.35	15.16	5.16	7.20	1.58	2.36	0	0	34.92	1867	30.64
1867–68.....	0	0	0.04	0.20	3.41	10.69	9.50	6.13	6.30	2.31	0.03	0.23	38.84	1868	30.17
1868–69.....	0	0	0	0.15	1.18	4.34	6.35	3.90	3.14	2.19	0.08	0.02	21.35	1869	22.59
1869–70.....	0	0	0.12	1.29	1.19	4.31	3.89	4.78	2.00	1.53	0.20	0	19.31	1870	16.24
1870–71.....	0	0	0.03	0	0.43	3.38	3.07	3.76	1.05	1.89	0.23	0.01	14.11	1871	27.53
1871–72.....	0	0.02	0	0.07	2.81	14.36	4.00	6.90	1.59	0.81	0.18	0.04	30.78	1872	22.45
1872–73.....	0.01	0	0.04	0.11	2.79	5.95	1.58	3.94	0.78	0.43	0	0.02	15.66	1873	18.55
1873–74.....	0.01	0.08	0	0.83	1.16	9.72	5.66	2.21	3.36	0.90	0.66	0.14	24.73	1874	22.52
1874–75.....	0	0	0.02	2.69	6.55	0.33	8.01	0.32	1.30	0.10	0.22	1.02	20.56	1875	22.63
1875–76.....	0	0	0	0.24	7.27	4.15	7.55	4.92	5.49	1.29	0.24	0.04	31.19	1876	23.54
1876–77.....	0.01	0.01	0.38	3.36	0.25	0	4.32	1.18	1.08	0.26	0.18	0.01	11.04	1877	11.93
1877–78.....	0.02	0	0	0.65	1.57	2.66	11.97	12.52	4.56	1.06	0.16	0.01	35.18	1878	33.26
1878–79.....	0.01	T.	0.55	1.27	0.57	0.58	3.52	4.90	8.75	1.89	2.35	0.05	24.44	1879	30.76
1879–80.....	0.01	0.02	T.	0.78	4.03	4.46	2.23	1.87	2.08	10.06	1.12	0	26.66	1880	30.07
1880–81.....	0	0	0	0.05	0.33	12.33	8.69	4.65	0.90	0.06	0.22	0.69	29.86	1881	23.73
1881–82.....	0	0	0.25	0.54	1.94	3.85	1.68	4.66	3.45	2.00	0.21	0.04	16.14	1882	18.67
1882–83.....	0	0	0.26	2.66	4.18	2.01	1.92	1.04	3.01	1.51	3.52	0.01	20.12	1883	15.43
1883–84.....	0	0	0.42	1.48	1.60	0.92	3.94	6.65	8.24	6.33	0.23	2.57	32.38	1884	38.82
1884–85.....	T.	0.04	0.33	2.55	0.26	7.68	2.53	0.30	1.01	3.17	0.04	0.19	18.10	1885	24.90
1885–86.....	0.06	T.	0.11	0.72	11.78	4.99	7.42	0.24	2.07	5.28	0.37	0.01	33.06	1886	20.02
1886–87.....	0.23	T.	0.01	1.48	0.84	2.07	1.90	9.24	0.84	2.30	0.06	0.07	19.04	1887	19.04
1887–88.....	T.	0.01	0.29	T.	0.99	3.34	6.81	0.94	3.60	0.11	0.38	0.27	16.74	1888	23.03
1888–89.....	0.01	0.01	0.96	0.13	3.99	5.80	1.28	0.72	7.78	0.99	2.17	0.03	23.86	1889	36.94
1889–90.....	0.01	T.	T.	7.28	2.90	13.81	9.61	5.16	4.73	1.18	1.07	0.10	45.85	1890	25.43
1890–91.....	0.02	0	0.31	0	0	3.25	0.98	7.26	1.96	2.44	1.25	0.11	17.58	1891	21.11
1891–92.....	0.10	0.02	0.77	0.04	0.56	5.62	2.42	2.90	2.85	1.39	1.86	T.	18.53	1892	22.08
1892–93.....	0	0	0.02	1.65	3.91	5.08	3.06	2.75	4.08	1.03	0.15	0.03	21.75	1893	17.91
1893–94.....	0.02	0	0.21	0.16	4.18	2.25	5.99	2.69	0.60	0.50	1.31	0.56	18.47	1894	24.32



TABLE 8.—San Francisco rainfall, monthly, seasonal, and annual, 1849-1912—Continued.

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Seasonal.	Year.	Annual.
1894-95.....	T.	0	1.05	1.73	0.88	9.01	6.99	2.31	1.89	1.24	0.60	0	25.70	1895	17.13
1895-96.....	0.01	0	0.77	0.11	1.78	1.43	8.14	0.28	2.85	5.16	0.72	0	21.25	1896	28.25
1896-97.....	0.04	0.09	0.52	1.55	4.56	4.34	2.26	4.41	4.56	0.27	0.61	0.22	23.43	1897	16.40
1897-98.....	T.	T.	0.10	1.70	1.05	1.22	1.12	2.13	0.24	0.19	1.44	0.19	9.38	1898	9.31
1898-99.....	0	T.	1.06	0.86	0.46	1.62	3.67	0.10	7.61	0.62	0.86	0.01	16.87	1899	23.23
1899-1900.....	0	T.	0	3.92	3.79	2.65	4.11	0.64	1.91	1.08	0.32	0.05	18.47	1900	15.33
1900-1901.....	T.	T.	0.46	1.48	3.91	1.37	5.79	5.03	0.80	1.64	0.69	T.	21.17	1901	19.75
1901-2.....	T.	T.	0.78	0.64	3.48	0.90	1.23	7.27	2.65	0.98	1.05	0	18.98	1902	19.18
1902-3.....	T.	T.	T.	1.70	1.98	2.32	3.73	1.76	6.23	0.56	T.	T.	18.28	1903	18.33
1903-4.....	0	T.	T.	0.17	4.25	1.63	1.05	5.89	6.01	1.29	0.30	T.	20.59	1904	24.72
1904-5.....	0.02	0.06	5.07	2.37	1.07	1.59	4.04	2.70	3.15	1.33	2.05	0	23.45	1905	16.24
1905-6.....	0	T.	T.	T.	0.92	2.05	3.90	4.30	5.02	0.92	2.75	0.56	20.42	1906	26.34
1906-7.....	0.08	0.11	0.18	0.03	1.59	6.90	4.41	3.02	8.42	0.11	0.04	1.28	26.17	1907	22.47
1907-8.....	T.	0.02	0.11	1.36	0.04	3.66	4.88	5.39	0.90	0.22	0.76	0.01	17.35	1908	16.42
1908-9.....	0.02	0.01	0.13	0.61	1.34	2.15	10.51	7.53	3.27	T.	T.	T.	25.57	1909	31.36
1909-10.....	0	T.	0.80	1.23	2.43	5.59	3.24	2.09	3.78	0.31	0.03	0.02	19.52	1910	12.38
1910-11.....	T.	0	0.05	0.65	0.48	1.73	13.79	3.02	4.57	0.89	0.28	0.03	25.49	1911	26.00
1911-12.....	T.	0	T.	0.28	0.60	2.54	2.47	0.41	4.10	1.38	1.47	0.81	14.06	1912	15.62
1912.....	T.	0	1.25	0.49	1.94	1.30	.....	.....	.....	.....	.....	.....	.....	.....	.....
Averages.....	0.02	0.02	0.32	1.00	2.55	4.51	4.90	3.55	3.36	1.64	0.73	0.16	22.58	.....	22.60

TABLE 9.—*Greatest precipitation (inches and hundredths) in twenty-four hours for each month.*

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Greatest annual.
1871.....			0.57	1.28	0.13	0.01	0.00	0.02	0.00	0.07	1.24	3.14	3.14
1872.....	2.36	1.28	0.73	0.35	0.15	0.03	0.01	0.00	0.04	0.11	2.06	2.33	2.36
1873.....	1.02	0.82	0.54	0.36	0.00	0.01	0.01	0.06	0.00	0.77	0.80	2.33	2.33
1874.....	1.61	0.81	0.65	0.70	0.23	0.13	0.00	0.00	0.02	1.18	3.98	0.15	3.98
1875.....	2.19	0.27	0.45	0.06	0.14	0.90	0.00	0.00	0.00	0.22	2.37	1.50	2.37
1876.....	1.76	1.80	1.19	0.60	0.24	0.04	0.01	0.01	0.20	1.39	0.19	0.00	1.80
1877.....	1.63	0.52	0.56	0.08	0.18	0.01	0.02	0.00	0.00	0.36	0.16	1.11	1.63
1878.....	1.98	1.92	1.01	0.61	0.14	0.01	0.01	T.	0.45	1.27	0.45	0.33	1.98
1879.....	1.04	1.66	3.31	0.72	0.93	0.05	0.01	0.02	T.	0.56	1.38	1.55	3.31
1880.....	1.03	0.64	0.57	2.21	0.84	0.00	0.00	0.00	0.00	0.05	0.32	2.36	2.36
1881.....	4.67	1.37	0.69	1.09	0.17	0.41	0.00	0.00	0.25	0.21	1.34	1.35	4.67
1882.....	0.57	0.82	0.86	0.44	0.15	0.02	0.00	0.00	0.26	1.40	2.41	0.76	2.41
1883.....	1.30	0.71	1.63	0.76	1.23	0.01	0.00	0.00	0.42	1.19	1.01	0.28	1.63
1884.....	1.44	1.62	2.21	1.66	0.12	1.23	0.00	0.03	0.21	1.15	0.19	2.07	2.21
1885.....	0.97	0.15	0.55	2.03	0.04	0.10	0.05	T.	0.11	0.70	2.58	2.78	2.78
1886.....	2.40	0.18	0.65	1.36	0.21	0.01	0.23	0.00	0.01	0.72	0.77	1.10	2.40
1887.....	0.80	3.60	0.52	1.45	0.03	0.07	T.	0.01	0.18	0.00	0.48	1.14	3.60
1888.....	1.58	0.38	1.34	0.11	0.19	0.10	0.01	0.01	0.92	0.05	1.68	1.51	1.68
1889.....	0.81	0.59	3.08	0.30	1.29	0.03	0.01	T.	T.	2.03	0.92	1.46	3.08
1890.....	2.08	1.63	1.86	0.55	0.53	0.05	0.02	0.00	0.31	0.00	0.00	1.90	2.08
1891.....	0.75	3.38	0.68	1.20	0.61	0.10	0.09	0.02	0.63	0.03	0.28	2.21	3.38
1892.....	1.06	1.03	0.90	0.38	1.15	T.	0.00	0.00	0.02	0.91	1.46	2.34	2.34
1893.....	1.39	1.06	0.98	0.71	0.14	0.03	0.02	0.00	0.12	0.10	1.69	0.97	1.69
1894.....	2.61	1.05	0.34	0.30	0.68	0.22	T.	0.00	1.04	0.64	0.88	1.64	2.61
1895.....	1.96	1.44	0.67	0.89	0.27	0.00	0.01	0.00	0.62	0.06	1.06	0.51	1.96
1896.....	1.85	0.18	0.84	2.43	0.34	0.00	0.04	0.06	0.41	1.46	2.79	1.65	2.79
1897.....	1.08	1.23	1.42	0.20	0.61	0.19	T.	T.	0.08	1.41	0.42	1.02	1.42
1898.....	0.33	0.78	0.13	0.19	1.23	0.18	0.00	T.	0.73	0.45	0.36	0.70	1.23
1899.....	0.98	0.08	2.15	0.45	0.77	0.01	0.00	T.	0.00	1.94	1.51	1.17	2.15
1900.....	1.92	0.50	0.90	0.36	0.22	0.04	T.	T.	0.45	0.34	1.66	0.74	1.92
1901.....	1.75	1.95	0.67	0.88	0.46	T.	T.	T.	0.67	0.43	1.20	0.01	1.95
1902.....	0.35	1.08	0.69	0.23	0.56	0.00	T.	T.	T.	0.69	0.77	0.85	1.08
1903.....	1.00	0.63	1.30	0.39	T.	T.	0.00	T.	T.	0.15	2.39	1.06	2.39
1904.....	0.59	2.73	1.32	0.40	0.30	T.	0.02	0.05	3.58	0.72	0.56	0.57	3.58
1905.....	1.08	1.23	0.93	0.49	1.18	0.00	0.00	T.	T.	T.	0.38	0.65	1.23
1906.....	1.06	1.32	1.37	0.51	1.42	0.23	0.05	0.08	0.12	0.91	0.67	2.57	2.47
1907.....	0.91	1.52	1.82	0.08	0.02	0.74	T.	0.02	0.11	0.99	0.02	0.96	1.82
1908.....	2.10	2.04	1.41	0.10	0.24	0.01	0.02	0.01	0.10	0.44	0.70	0.99	2.10
1909.....	1.61	1.87	1.16	T.	T.	T.	T.	0.00	0.67	0.82	0.97	1.41	1.87
1910.....	0.83	0.64	1.17	0.23	0.02	0.02	T.	0.00	0.04	0.48	0.27	0.99	1.17
1911.....	2.48	0.68	1.98	0.81	0.15	0.03	T.	0.00	T.	0.16	0.45	0.66	2.48
1912.....	1.05	0.19	2.09	0.80	0.74	0.68	T.	0.00	1.21	.....	.....	.....	.....
Year.....	4.67	3.60	3.31	2.43	1.42	1.23	0.23	0.08	3.58	2.03	3.98	3.14	4.67

Dates when the precipitation equaled or exceeded 2.50 inches in any consecutive 24 hours: 1871, December 17–18, 2.83 inches; 1871, December 18–19, 3.14 inches; 1874, November 22–23, 3.98 inches; 1879, March 4–5, 3.31 inches; 1881, January 28–29, 4.67 inches; 1885, November 23–24, 2.58 inches; 1885, December 21, 2.78 inches; 1887, February 4–5, 3.60 inches; 1889, March 12–13, 3.08 inches; 1891, February 14–15, 3.38 inches; 1894, January 19–20, 2.61 inches; 1896, November 23–24, 2.79 inches; 1904, February 11–12, 2.73 inches; 1904, September 23, 3.58 inches.

Maximum rates of rainfall: 1901, February 22, 5 minutes, 0.17 of an inch; 10 minutes, 0.21; 1902, October 23, 5 minutes, 0.16 of an inch; 10 minutes, 0.20; 1903, February 7, 5 minutes, 0.19 of an inch; 10 minutes, 0.23; 1904, September 23, 5 minutes, 0.16 of an inch; 10 minutes, 0.32; 1904, September 23, in 15 minutes, 0.43; in 30 minutes, 0.74; in 1 hour, 0.97; in 2 hours, 1.29; in 16 hours 15 minutes, 3.58 inches; 1912, March 5, 5 minutes, 0.10; 10 minutes, 0.28; 15 minutes, 0.53; 20 minutes, 0.72; 25 minutes, 0.77; and 30 minutes, 0.78 of an inch.

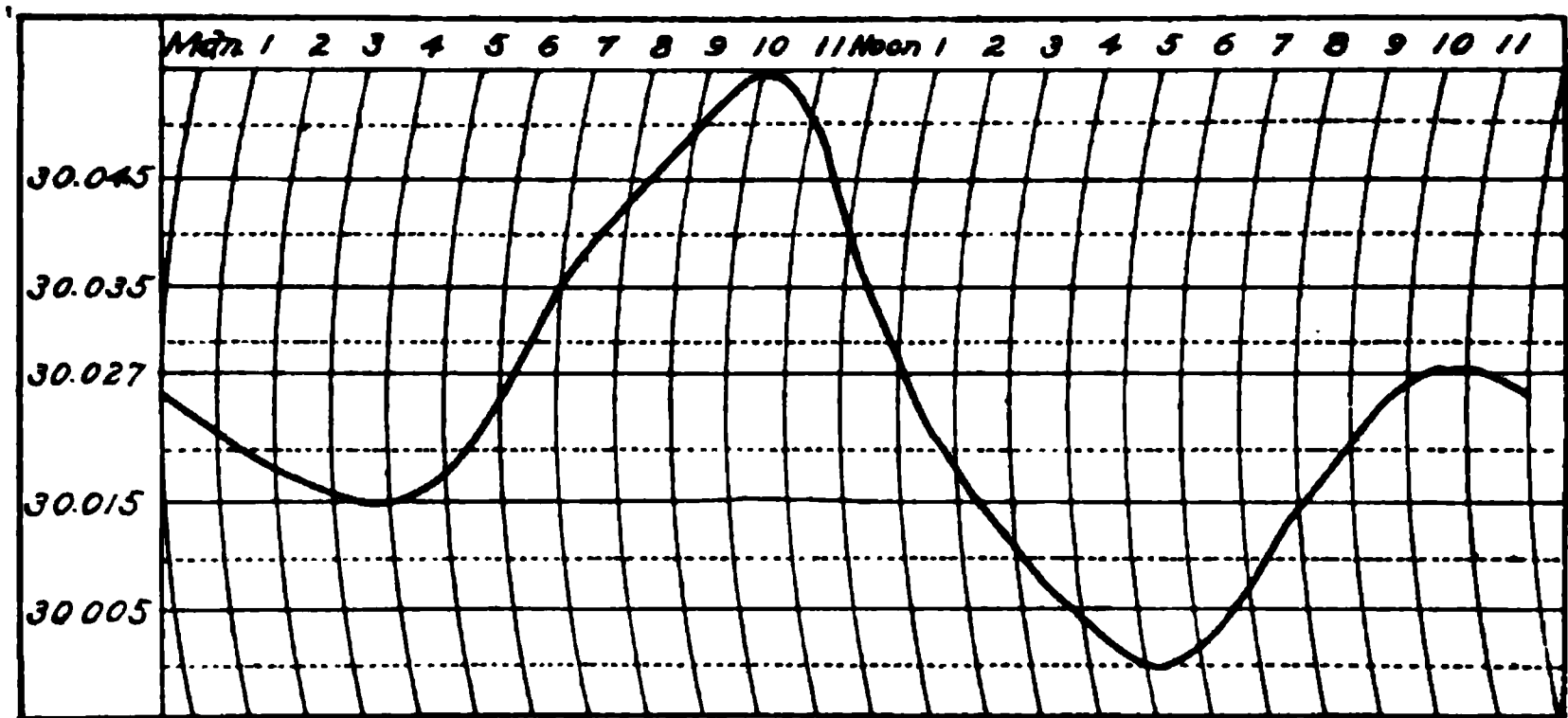


FIG. 1.—Hourly pressure, San Francisco. (Sea level).

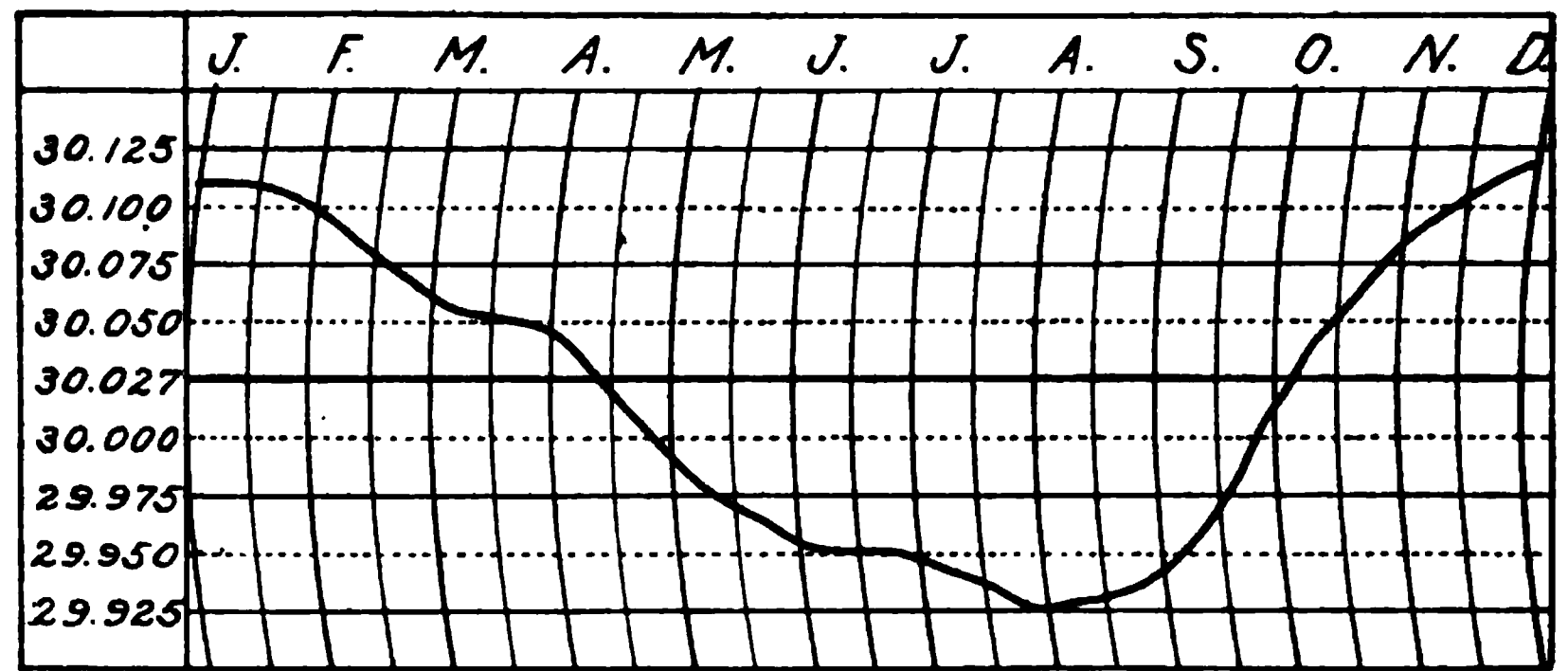


FIG. 2.—Monthly sea level pressure, San Francisco.

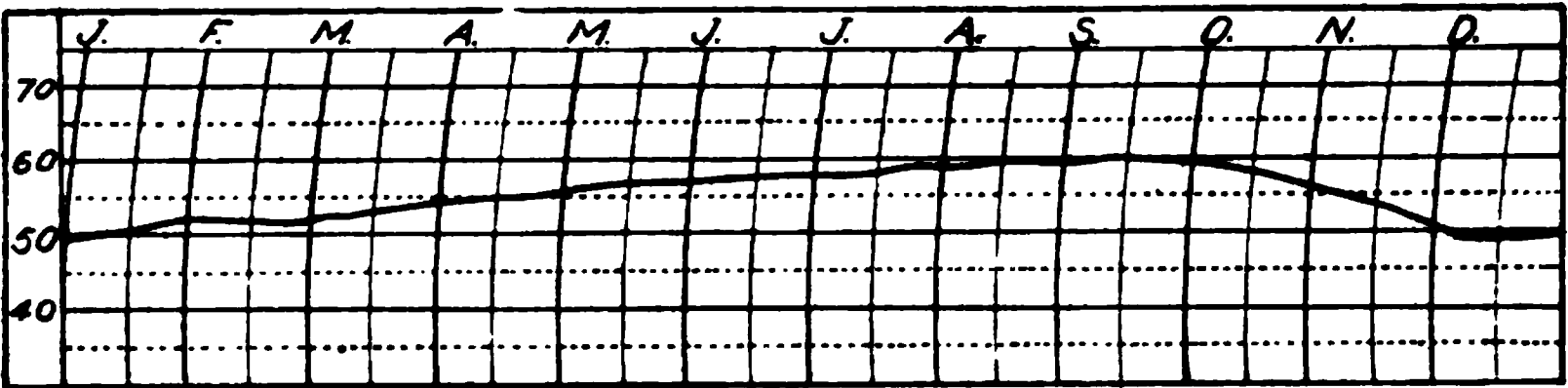


FIG. 3.—Mean monthly temperature at San Francisco, 1891-1910.

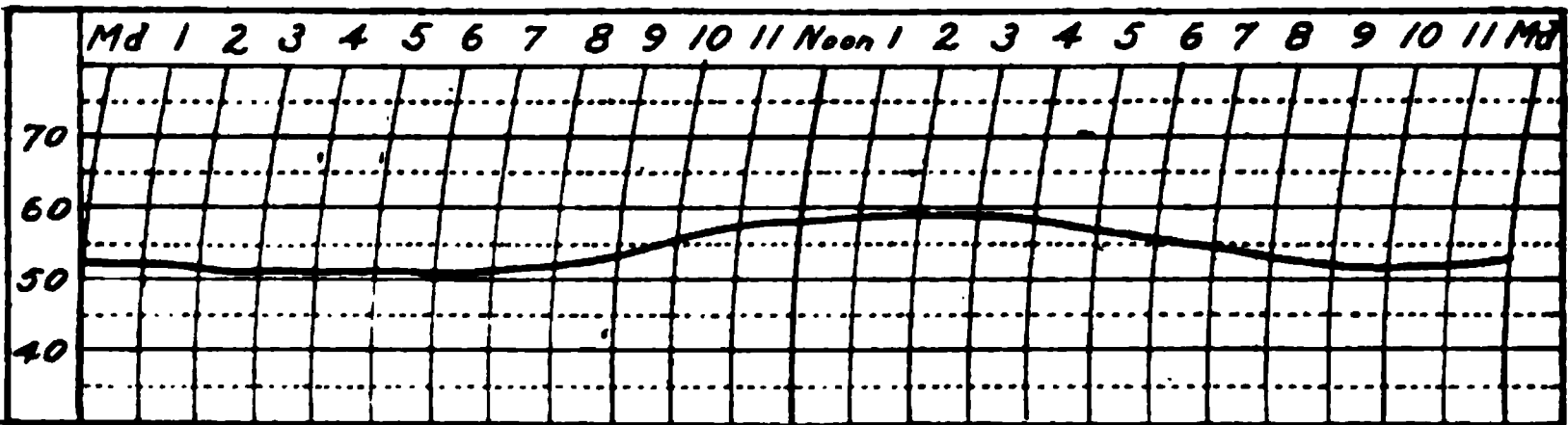


FIG. 4.—Average hourly temperature at San Francisco, 1891-1910.

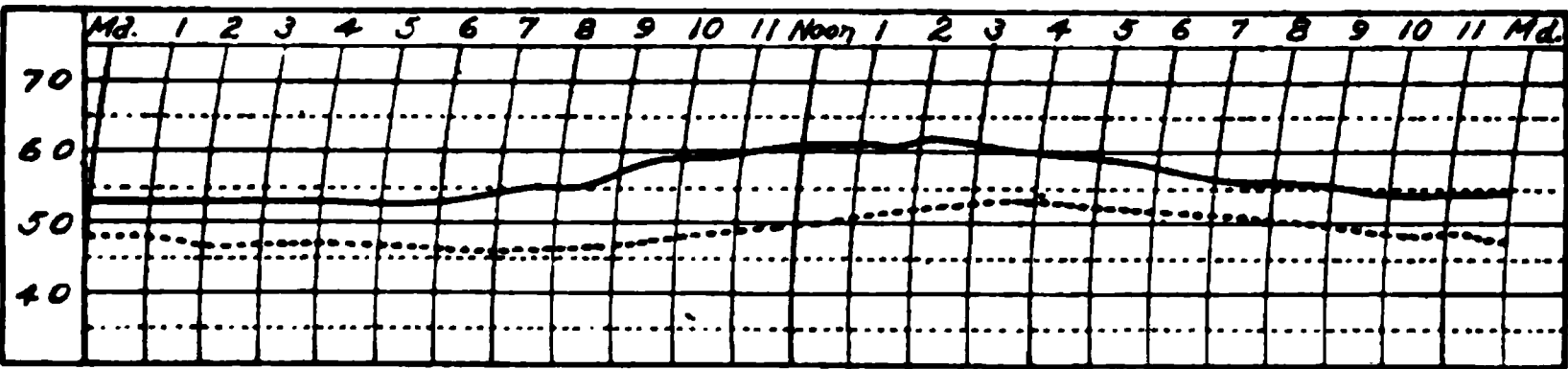


FIG. 5. —Mean hourly temperature Summer —, winter .....

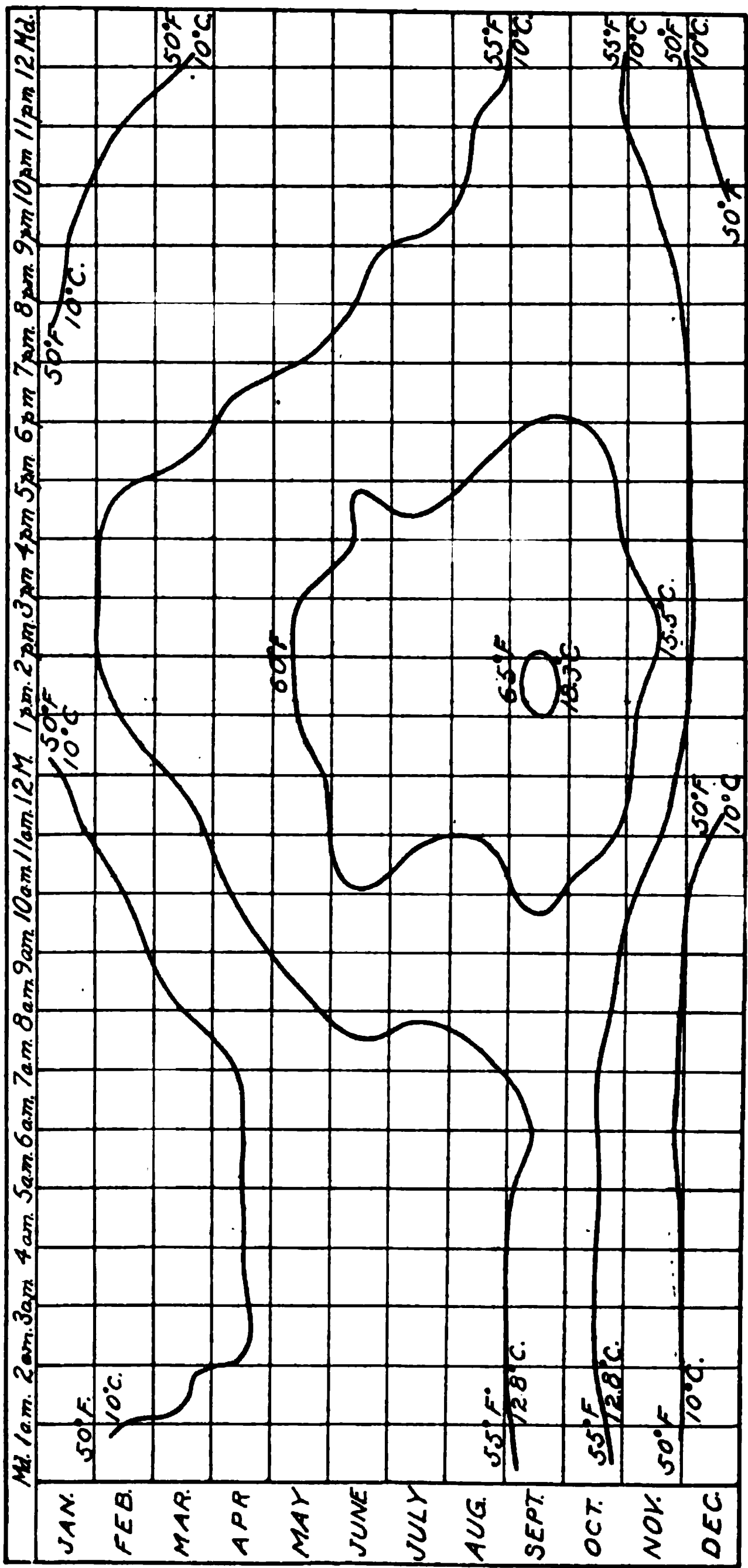


FIG. 6.—Isopleth of temperature at San Francisco, 1891-1910.

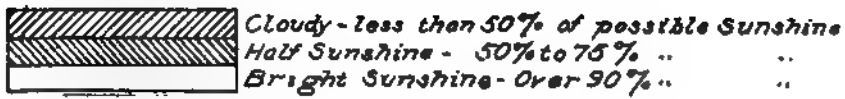


FIG. 7.—Sunshine at San Francisco, 1893-1911.

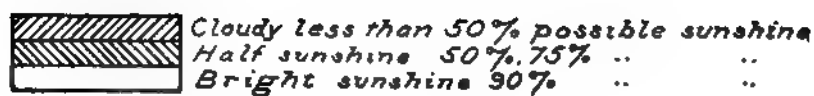


FIG. 8.—Sunshine at Mount Tamalpais, 1891-1911.

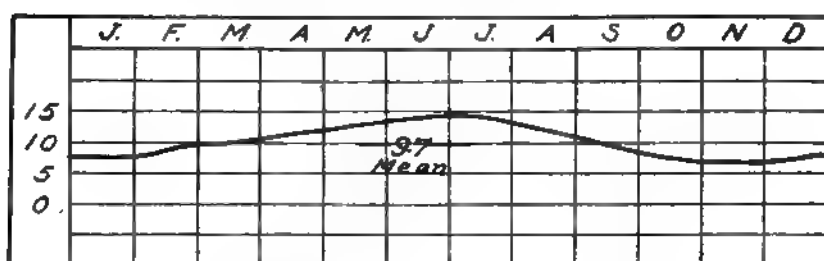


FIG. 9.—Average monthly wind velocity, 1891-1910.

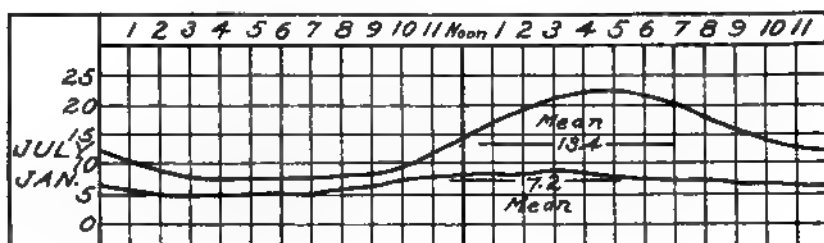


FIG. 10.—Hourly wind velocity, 1891-1910.

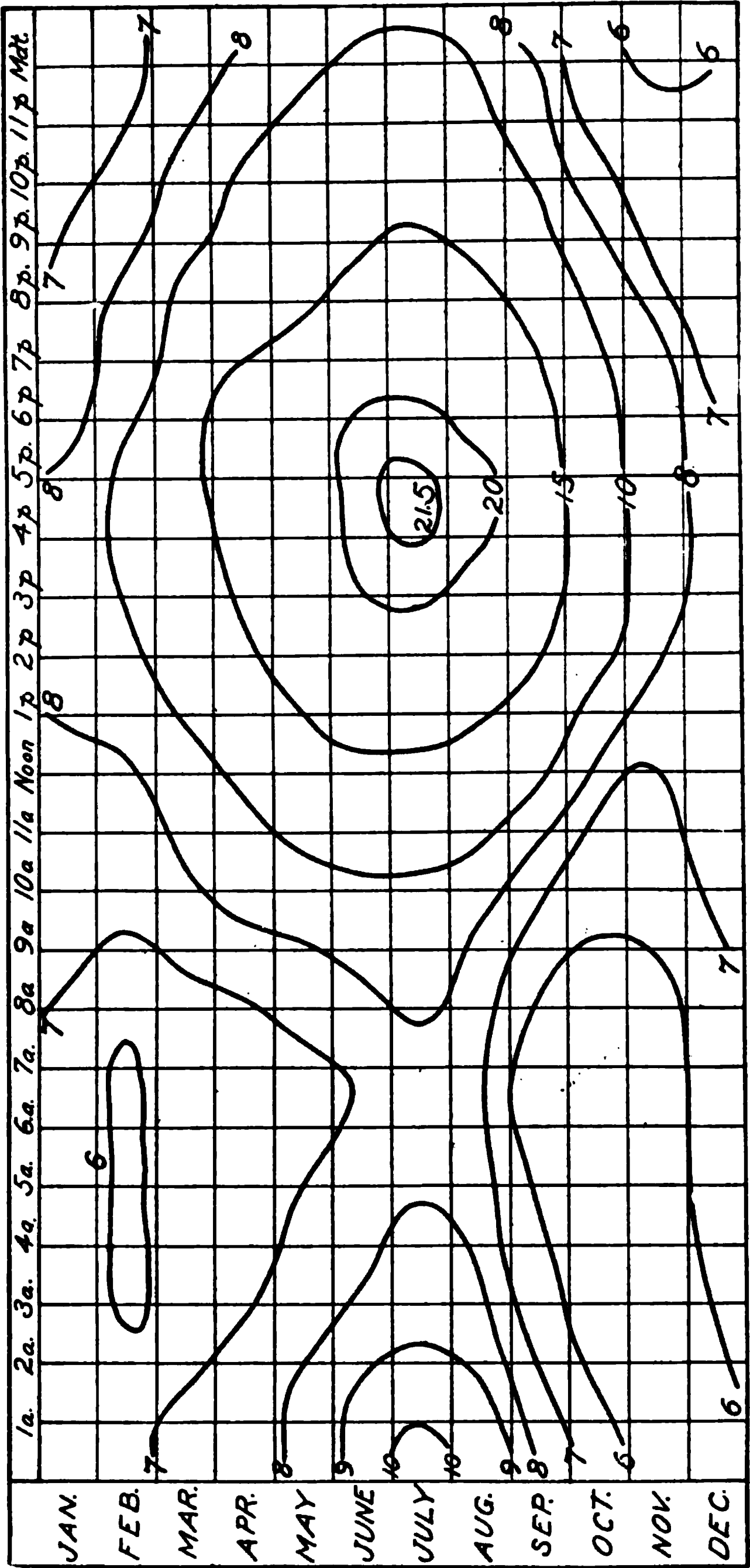


FIG. 11.—Isopleth of wind, San Francisco, 1891-1910.



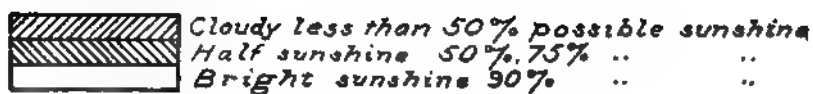


FIG. 8. — Sunshine at Mount Tamalpais, 1890-1911.

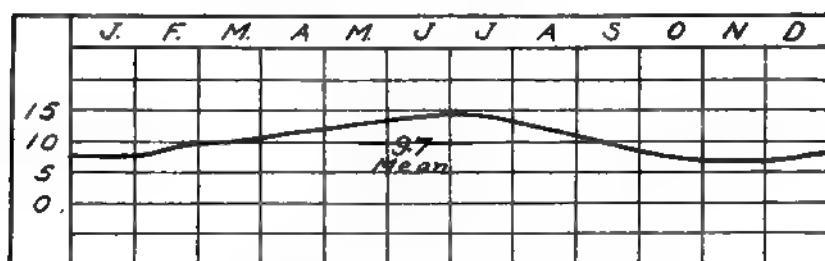


FIG. 9. — Average monthly wind velocity, 1891-1910.

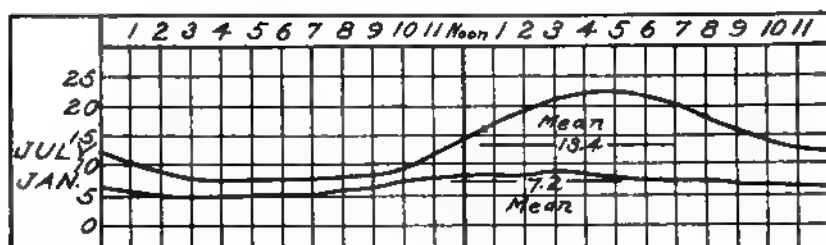


FIG. 10. — Hourly wind velocity, 1891-1910.

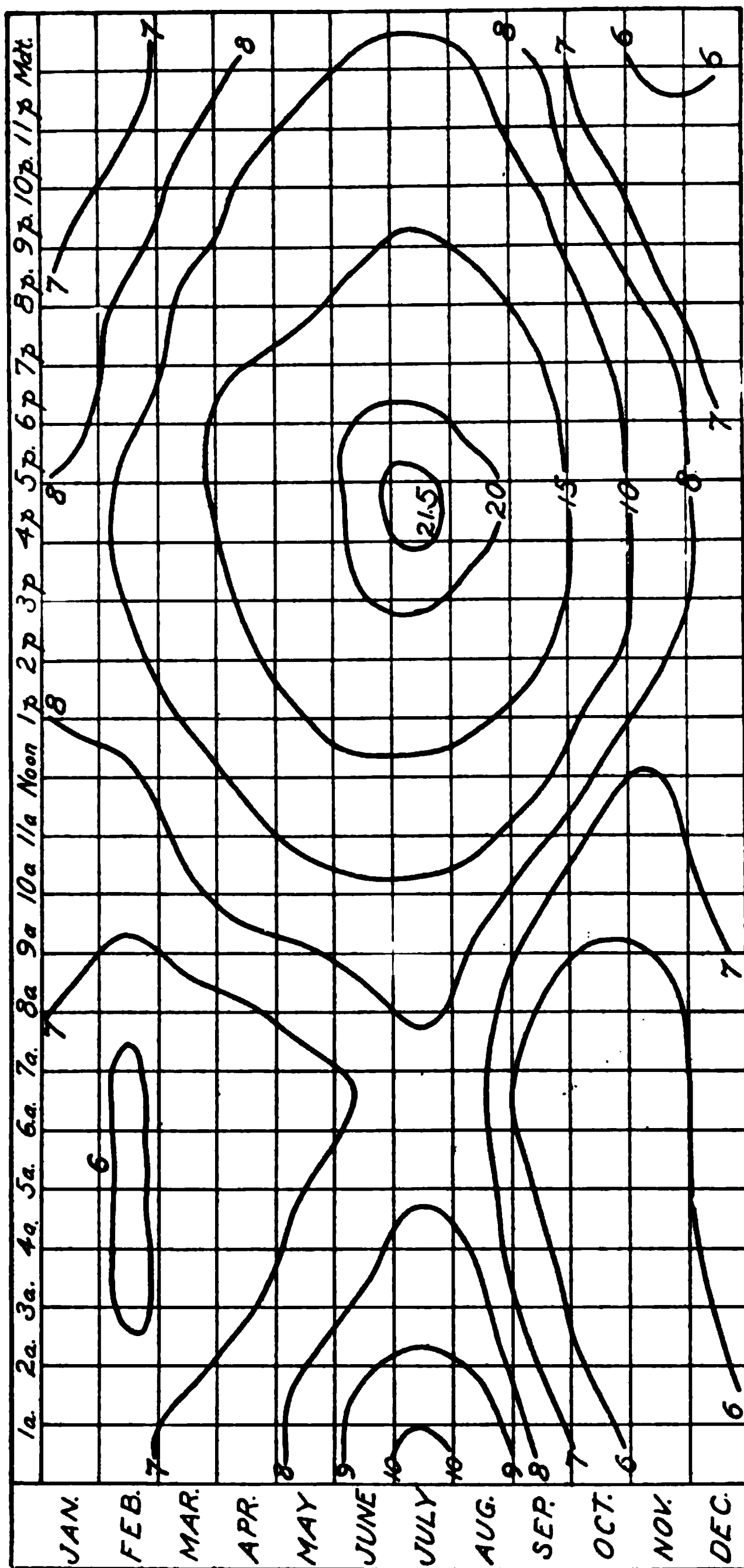


FIG. 11.—Isopleth of wind, San Francisco, 1891-1910.

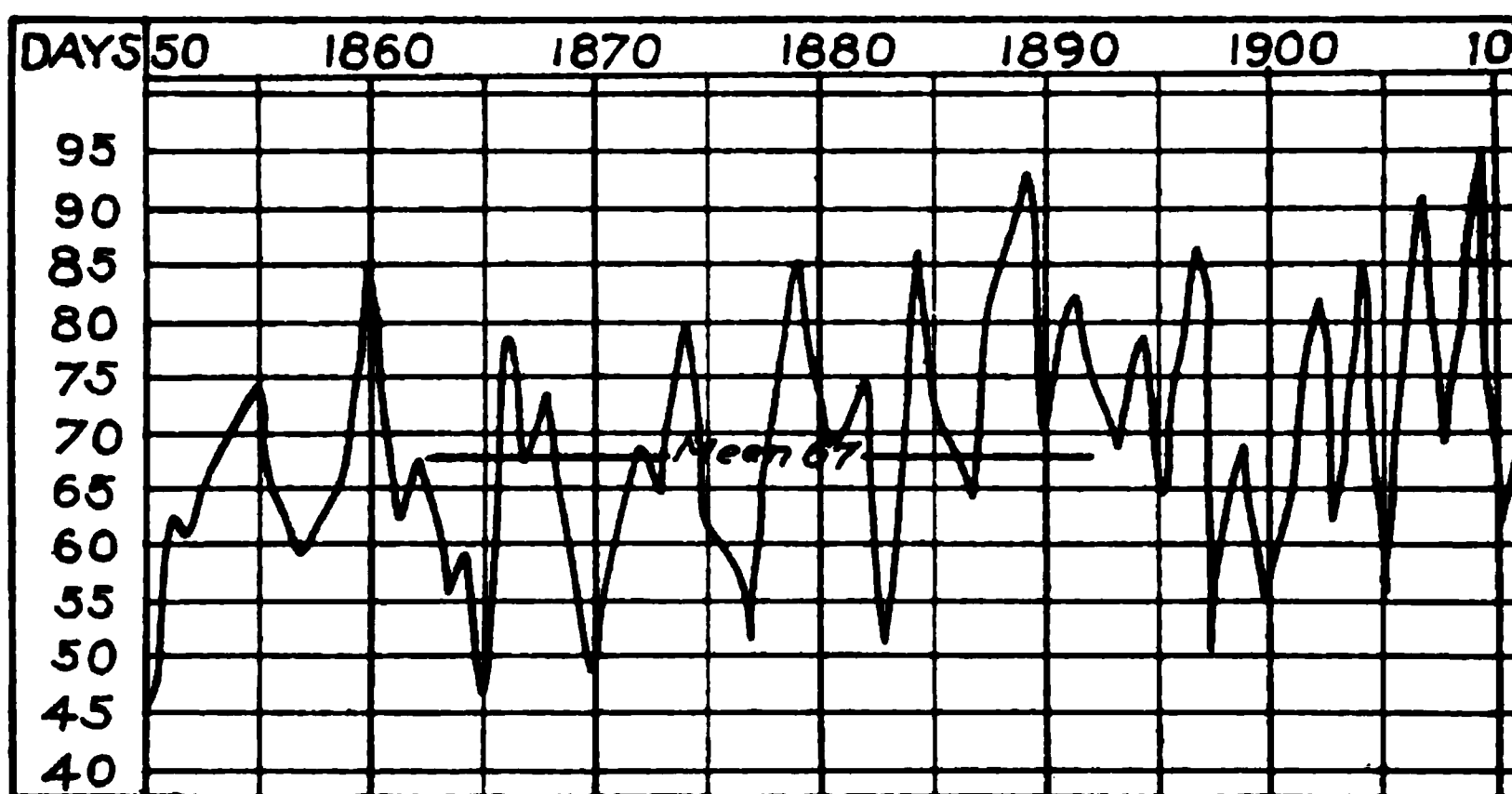


FIG. 12.—Annual frequency of rainy days, San Francisco.

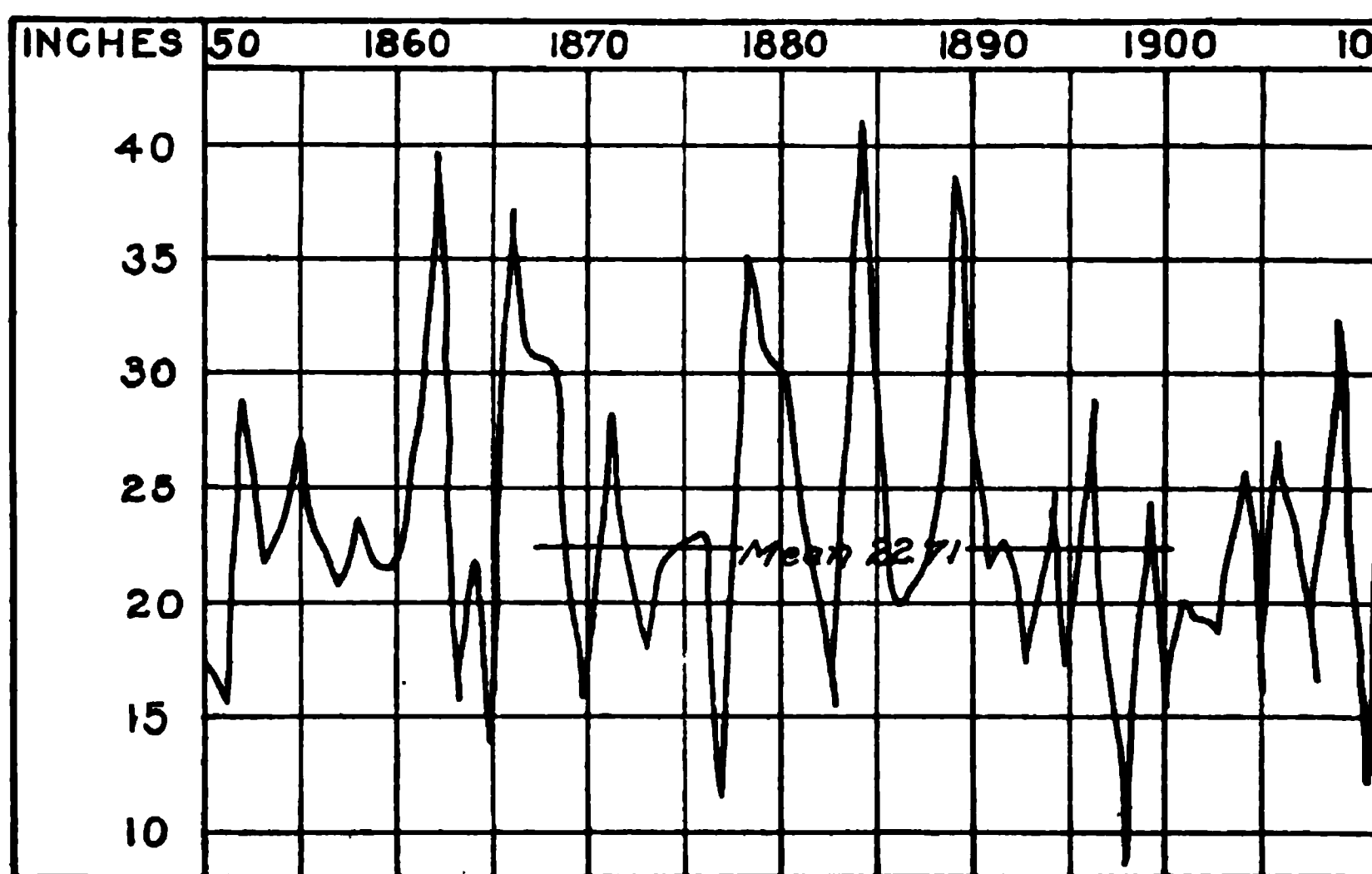


FIG. 13.—Annual rainfall at San Francisco, 1850-1911.

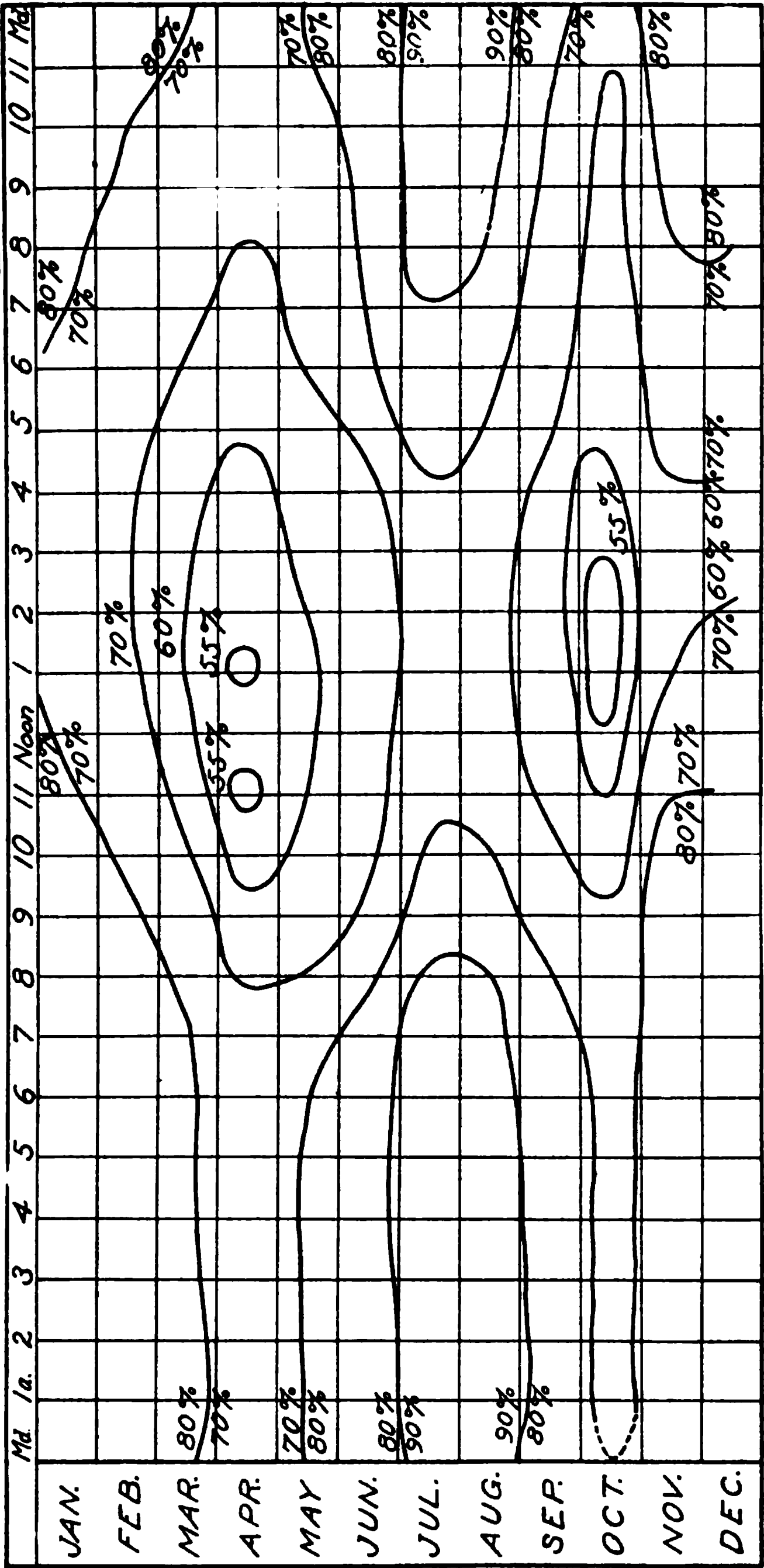


FIG. 14.—Isopleth of relative humidity, 1908-1909, San Francisco.













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